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COMBAT SOUND DETECTION: I. MONAURAL LISTENING IN QUIET

HUMAN ENGINEERING LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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G. Richard Price
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The presence of enemy personnel is often revealed by the noises they or their equipment make. However, we know very little of the factors which affect the detection of complex transient sounds made under these conditions. A predictive model was devised which took account of the spectral and temporal distribution of energy in the sounds, and the spectral sensitivity of the ears detecting them. Predictions were compared with actual detections for 20 ears as they listened for 24 different recorded sounds (walking noises, rifle bolt, etc.). Correlations between predictions and detections ranged from .89 to .98. The same model was then used with data from a recent

(Continued)

20. ABSTRACT (Continued)

survey of hearing in the combat arms to predict detection of the same sounds. Under quiet laboratory conditions the young, normal ears would have detected sounds about 16 dB less intense than the old Army ears could; however, when background noises for even quiet countryside or jungle were added, the predicted differences in detection levels were minimal. Preliminary data indicate that simple detection (the performance measured in these studies) does not reveal the true differences between ears with hearing losses and those in the normal range. Auditory performance is expected to be best described by the ear's ability to identify the sounds, rather than simply detect them. Future research is directed toward understanding this performance and deriving a predictive scheme for it.

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APPROVED: John D. Weisz
JOHN D. WEISZ
Director
U. S. Army Human Engineering Laboratory

U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005

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COMBAT SOUND DETECTION: I. MONAURAL LISTENING IN QUIET[a]

INTRODUCTION

The current emphasis of the psychoacoustics program at the Human Engineering Laboratory is on the hearing-performance requirements of soldiers, and the effect of hearing loss on soldiers' performance. Concisely, we want to find out what you have to be able to hear to perform satisfactorily in the Army, and how hearing losses affect this performance.

BACKGROUND CONSIDERATIONS

This program has evolved from a variety of considerations. First, no detailed catalog of hearing-performance requirements exists. Second, noise-induced hearing loss is a very significant Army problem; in fact, noise has been called the Army's number-one occupational hazard. Walden's data (8) indicate that it takes only a very few years of Army service for a significant degree of hearing loss to become evident in the infantry, armor and artillery branches. Another consideration is the obvious fact that aural communication is an important aspect of the soldier's activity in combat; anything that degrades his ability to hear is likely to degrade his performance. By "communication" we refer not only to the reception of speech but, and perhaps more important, the reception of sounds that betray the presence of the enemy. Particularly under conditions of limited visibility, whether imposed by terrain, vegetation, or darkness, the sense of hearing is vital to the soldier in informing him of the enemy's presence and activities (6). A fourth factor that led to the development of this program is the difficulty of predicting the effects of hearing loss (temporary or permanent) on soldiers' performance. Even for speech reception, which has been researched for over 40 years, consensus has not been completely reached as to how much hearing loss constitutes impairment of speech reception, particularly under real-world listening conditions. For other aspects of communication, such as the detection and identification of combat sounds, predictions have been impossible up to this time. A related consideration is that past noise-effects research has provided a body of data from which hearing loss can be predicted, given a knowledge of the noise-exposure parameters. However, it is not feasible at this time to translate these predictions into reliable estimates of decrement in combat-skill performance.

Our preliminary assessment of soldiers' tasks in combat (5) revealed that of the three primary soldier skills– "move, shoot, communicate"– communication was the most likely to be affected by hearing loss. Within the area of communication, the primary problem appeared to be the detection and identification of enemy personnel sounds. Katzell et al. (6), in a survey of combat recognition requirements, showed that enemy personnel are the most important target for all types of military units in the field. The decision to embark on studies of the detection and identification of personnel sounds was further influenced by our spectrum analysis of a U.S. Navy training-aid tape recording. That analysis indicated that many of the personnel sounds had maximum energy in the 4-8 kHz region where, as is well known, noise-induced hearing loss is

[a]An abbreviated version of this paper was presented at the U.S. Army Science Conference, United States Military Academy, West Point, New York, June 1976.

often first observed. This suggested that hearing loss might pose a significant problem for the soldier who is attempting to detect the enemy's presence by the sounds of his movement.

BRIEF OF PHASE I OF THE PROGRAM

Two aspects of combat sounds are of concern: detection and identification. Detecting a complex transient sound implies that the listener hears something (in addition to the background noise), while identification means that the listener not only detects the sound but also associates a specific meaning with it, as determined from the sound's peculiar characteristics. In identification, the listener may be able to recognize the source of the sound, to associate it with friendly or unfriendly forces, etc. Thus, as a sound too faint to be heard is raised in intensity (e.g., when the source moves closer to the listener or vice versa), we expect detection to occur first and then, after a further increase in intensity, identification should become possible. In a combat listening situation, detection alerts the soldier that "something is out there." Identifying the sound's source, location, etc., enables the listener to take appropriate action.

Experiments on sound detection and sound identification require different approaches. Detection may be studied using techniques analogous to conventional audiometric threshold testing. In contrast, sound identification requires, among other things, that the listener be able to name the sound; thus he must be intimately familiar with all the test sounds. Since detection is therefore the simpler type of behavior, at least from a methodological standpoint, it was decided at the outset that the program would first emphasize the sound-detection aspect, and studies of sound identification would be deferred until after the detection phenomenon was better understood.

Another choice made in structuring a systematic approach to this program was that we should start with the simplest listening condition and proceed to more complex conditions. This paper reports on the initial tests conducted with monaural listening in quiet. We recognize this listening condition is not typical of the real world; however, it was felt that an understanding of this simple level should be gained before introducing other variables, such as binaural listening and listening in noise. Both of these types of conditions will be the subject of future experimentation.

In addition to comparing hearing levels measured by conventional audiometry with detection thresholds for transient, combat-relevant sounds, one of the primary goals of this first series of tests was to develop a model (hopefully predictive) of the detection of transient sounds by the ear, based on known functional characteristics of the auditory system. This aim was accomplished, and the report describes the development of a model which considers both the ear's analysis of frequency by critical bandwidths, and its integration of energy for periods up to 200 msec. This model, embodied in a computer program for analyzing complex, transient sounds, was found to predict relative detectability quite well, given a knowledge of the ear's sensitivity at the center frequencies of the critical bands.

METHOD

Selection of the Test Sounds

The choice of sounds used as stimuli in these experiments was dictated by both practical and theoretical considerations. As mentioned earlier, a general class of sounds thought to be of

very great practical significance was that associated with the presence of enemy personnel: sounds related to personnel movement, camp activity, personal combat equipment, etc. These are sounds that a sentry, listening post, or reconnaissance patrol would have to be able to detect to accomplish their missions (5). Failing to detect such sounds in combat could have life-and-death significance. Prior to this experiment, however, sounds of this type had never been measured in a way that permitted their detectability to be analyzed. Therefore it was necessary to record and analyze a set of sounds for use.

From the sounds that were recorded, 24 were selected for use in the test. They were: footfalls on leaves, sand, gravel, coarse gravel, in a puddle, on twigs, and on dry grass; trimming branches with a machete; chopping with a machete; movement through a sapling thicket and through a raspberry thicket (two sounds); an M16 magazine being inserted; an AK47 magazine being inserted under anechoic and reverberant conditions; an M16 being cocked; a 1906 Springfield rifle bolt being operated; a C-ration pack being opened; urination on the ground; the safety being released on an M16 and on an AK47; the entrenching tool being used as a hoe and as a shovel in gravel; and walking in high grass.

Recording the Test Sounds

Test sounds were recorded at Aberdeen Proving Ground, Maryland, during October and November 1975. The sounds were recorded at a tape speed of 15 IPS on a Nagra Model IV-S tape recorder, using a Sennheiser Model MKH105 condenser microphone. The exact procedure varied somewhat with the circumstances; however, the general practice was to repeat each sequence several times with the microphone pointed at the source of the sound and about one meter from it (somewhat farther when the recordings were done in either the anechoic chamber or the reverberant room). In order to insure both an undistorted recording and a wide dynamic range, recording levels were set so that the peak levels in the sound segment just fell short of the level that would saturate the tape. The combined recording system was essentially linear from 20 to 15,000 Hz. While a complete discussion of outdoor sound-recording techniques is beyond the scope of this report, it should be noted that nearly all of the test-sound segments recorded in June 1975 were contaminated by bob-white quail calls and were therefore unusable.

The experimental design called for presenting sounds approximately once per second during a period of threshold tracking. To obtain 1-second samples, the master tapes were analyzed, and the 1-second period with the most intense sound on it was removed and made into a loop. (The minimum usable loop size was 16 inches, which gave an actual repetition period of 1.07 seconds.) The sounds usually had short durations, with peak-intensity periods considerably shorter than 1 second; thus it was possible to make the necessary cuts and splices in the quiet intervals, so that the splicing itself did not introduce detectable transients. The loops were then played back and re-recorded on a Sony TC-366-4 tape deck for 1 minute at 7.5 IPS. This 1-minute tape was used for the listening tests.

Analyzing the Sounds

In developing the detection model, two basic properties of the ear were taken into account: the ear's variation in sensitivity as a function of frequency, and its ability to integrate energy for a period of up to 200 msec.

The ear's variation in sensitivity as a function of frequency was dealt with by first analyzing each test sound's frequency content; a Fourier analysis was performed to determine the spectral distribution of the energy. In performing this analysis, a number of practical compromises had to be made. First, the length of the sound segment analyzed determined the lowest frequency that could be represented accurately in the analysis. The rule of thumb is that the time window transformed has to be long enough to have at least five cycles of the lowest frequency of interest; this would argue for a relatively long window. However, we were also interested in looking at the fine structure of the sounds; this required the shortest possible window. The compromise arrived at was a 20-msec window, which set the low-frequency limit at 250 Hz. The digitizer's sampling frequency was 50 kHz, which meant that the highest frequency represented was 25 kHz. However, for a variety of reasons, the actual analysis used only frequencies below 12 kHz.

The output of the frequency-analysis program was the power in a fixed bandwidth (48.83 Hz) across the range of frequencies analyzed. The ear, however, does not respond as a fixed-bandwidth filter; rather, it appears to analyze sound as though it consisted of a series of 24 "critical bands" spanning the frequency range from 50 to 13,500 Hz. The total energy required for a sound to be heard remains constant so long as the energy is confined to a single critical band (4). The center frequencies, and upper and lower cutoff frequencies, of these critical bands have been empirically established for the normal ear (7). Therefore a computer program was written in BASIC to assemble the power into critical bands, and convert them into a pressure spectrum.

The model also took account of a second property of the auditory system: its ability to integrate energy for a period of up to 200 msec (3, 9). This means that if a 20-msec sound were just detectable, then 200 msec of the same sound would be detectable at a level 10 dB less intense. To account for this property of the auditory system, a Fourier analysis was performed for each successive 20 msec of the sound. Typically, the sounds analyzed were short: the durations of appreciable energy ranged from less than 200 msec to about 1 second. The Fourier analyses began during a quiet period and continued to the next quiet period. Following the frequency analyses of each 20-msec segment, the computer program integrated the energy present in each critical band for 10 analyses (200 msec). Then another integration was performed, displaced from the first by 20 msec. This process was repeated until all the 20-msec periods had been included. Finally, for each critical band, the 200-msec period with the greatest energy was selected as the one most likely to be detected. These values (critical bands and energy) were printed out for use in predicting detectability.

The foregoing analysis was carried out with the equipment diagrammed in Figure 1. Several repetitions of each sound of interest were recorded from the master-tape loop onto one channel of the Sony tape recorder, and trigger pulses were recorded on a second channel. A clock within the NIC-80 analyzer provided delays of up to 512 msec in 1-μsec increments, which allowed successive 20-msec segments of the sound to be analyzed. For longer delays, the taped trigger pulse triggered the oscilloscope, which in turn provided a delayed trigger pulse. In this fashion, signals of any length could be analyzed. The successive power spectra were stored on the disk, so they could be retrieved during later analysis. Pressure-vs.-time histories were written out on the X-Y plotter to assist in determining the exact beginning and end of the analysis period.

Measuring the Ears' Sensitivity

Application of the detection model required knowing the individual differences in the sensitivity of real ears, in addition to the analyses of the sounds' spectra and temporal distributions of energy. Pure-tone thresholds were measured for each ear of 10 subjects (nine men

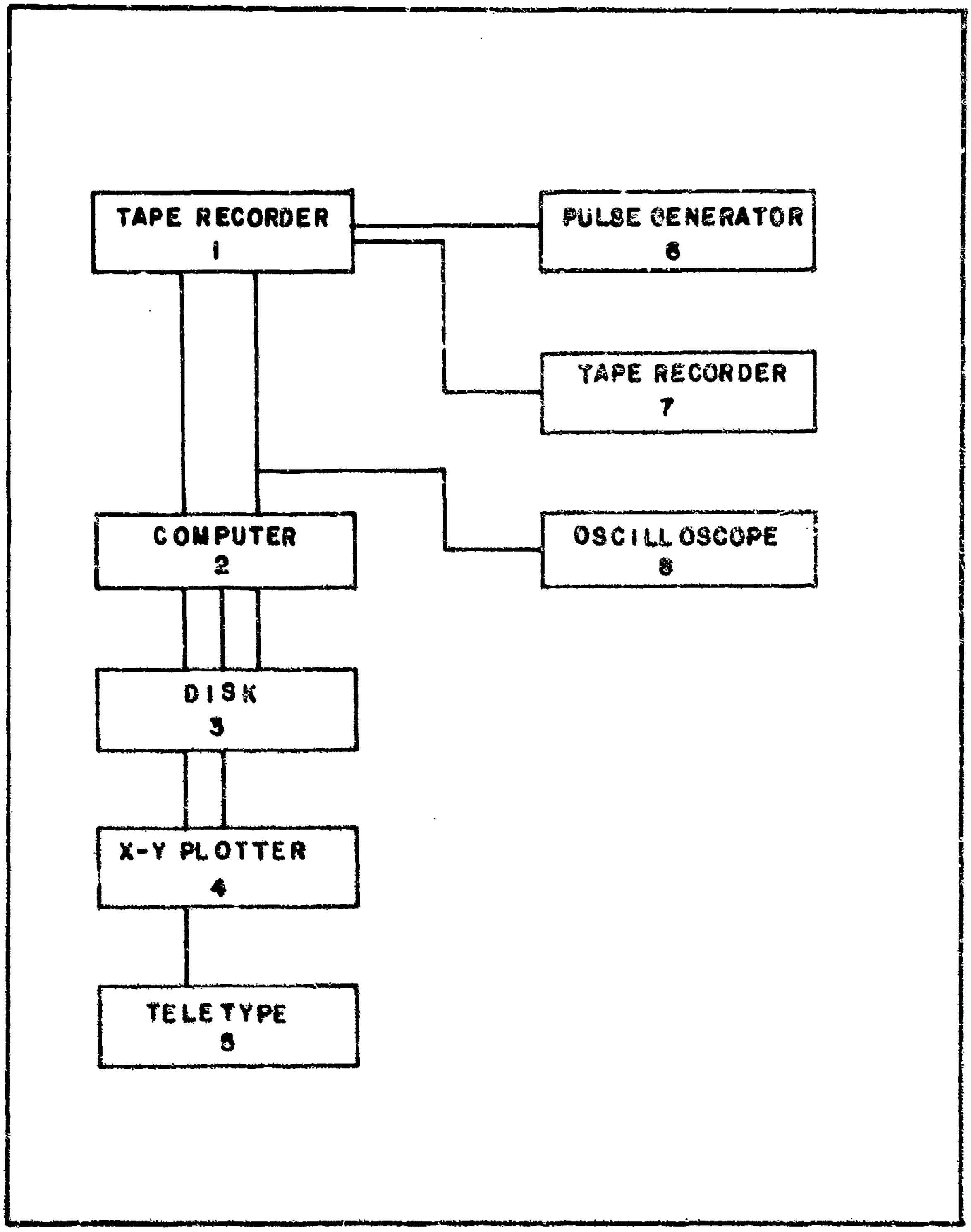

Figure 1. Instrumentation used in analyzing the spectrum of the test sounds. 1, Sony model TC-366-4 tape recorder. 2, Nicolet model NIC-80 data processor. 3, Diablo series 30 disk drive. 4, Hewlett-Packard model 7000 AM plotter. 5, Texas Instruments 160 series teletype. 6, Nagra model IV-S tape recorder. 7, Tektronix model 565 oscilloscope.

and one woman), using the same listening conditions that were used in the test for detecting the complex sounds. The equipment used for this purpose is diagrammed in Figure 2. Pure-tone stimuli were shaped into pulses with a 5-msec rise and fall time, and peak durations of either 17 or 197 msec. Based on the adjustment for rise-fall time established by Dallos and Olsen (1), the equivalent durations were 20 and 200 msec. The off periods were 980 and 800 msec, respectively, which resulted in a repetition period of 1 second.

The Sennheiser earphone used to transduce the signals was of the type that sets on a foam pad on the outside of the pinna. To prevent direct radiation of sound to the opposite ear, a circumaural ear muff was fitted to the earphone headband so the opposite ear was always covered. The shaper adjusted the earphone's acoustic output so it was flat (± 1dB) from 100 to 15,000 Hz. The equipment used in establishing this compensation is diagrammed in Figure 3. In essence, a pink-noise signal was fed into the shaper and then into the earphone, which was in place on an artificial ear. The output of the artificial ear was connected to a 1/3-octave real-time spectrum analyzer, and the shaper was adjusted to produce a flat spectrum.

The subjects were seated inside a double-walled acoustic test chamber and tracked their thresholds by activating a hand switch which controlled a recording attenuator operating at an attenuation rate of 4 dB/sec. Because of the amount of threshold tracking required of the subjects, frequent rest periods were given, and testing was broken up into separate sessions, often on different days. If the subject had any difficulty in tracking any sound, it was repeated until a reliable measure had been obtained. The combat sounds were presented in an order counterbalanced across all subjects. Tones for threshold tracking were presented for 30 sec at each of 22 critical-band center frequencies from 150 to 13,500 Hz (7). Thresholds were determined for both 20-msec and 200-msec on-times, in each ear of the 10 subjects, in the interest of determining how much temporal integration might be present. The subjects had been selected from among Laboratory personnel so as to have a wide range of hearing levels. Their ages ranged from 20 to 59 years, and none were known to be suffering from any otological problem at the time of the test (other than some high hearing levels). Their audiograms are attached in the Appendix.

From these threshold data, and the spectrum analyses of the sounds, it was possible to predict the relative detectability of the various complex sounds. The spectrum was plotted on one piece of graph paper, and the threshold curve on another. The two were overlaid on a light table, and the threshold curve was adjusted until the spectrum rose above the curve in one critical band. This point is illustrated in Figure 4. In this case, the spectrum for a footfall on leaves first met the threshold of audibility in band 13 (1850 Hz center frequency). The number assigned to this detection level for use in data analysis was established by an arbitrary procedure. A standard level was marked on the graphs of all spectra, and the position of this line was read with respect to the ordinate of the threshold curve. This number was recorded as the predicted detection level. By following this procedure, a prediction of relative detectability was obtained for each sound and each of the 20 ears.

In order to measure the detectability of the combat sounds, the oscillator was replaced by the tape deck and amplifiers diagrammed in Figure 2. Each subject could then track his threshold for the complex sounds. This threshold tracking continued for 1 minute for each sound in each ear. The thresholds thus determined were compared with the predicted detection levels established in the previous steps. Because the predicted detection level had been determined by comparison with an arbitrary level, the product-moment correlation coefficient was used to measure the relationship between actual and predicted detection levels.

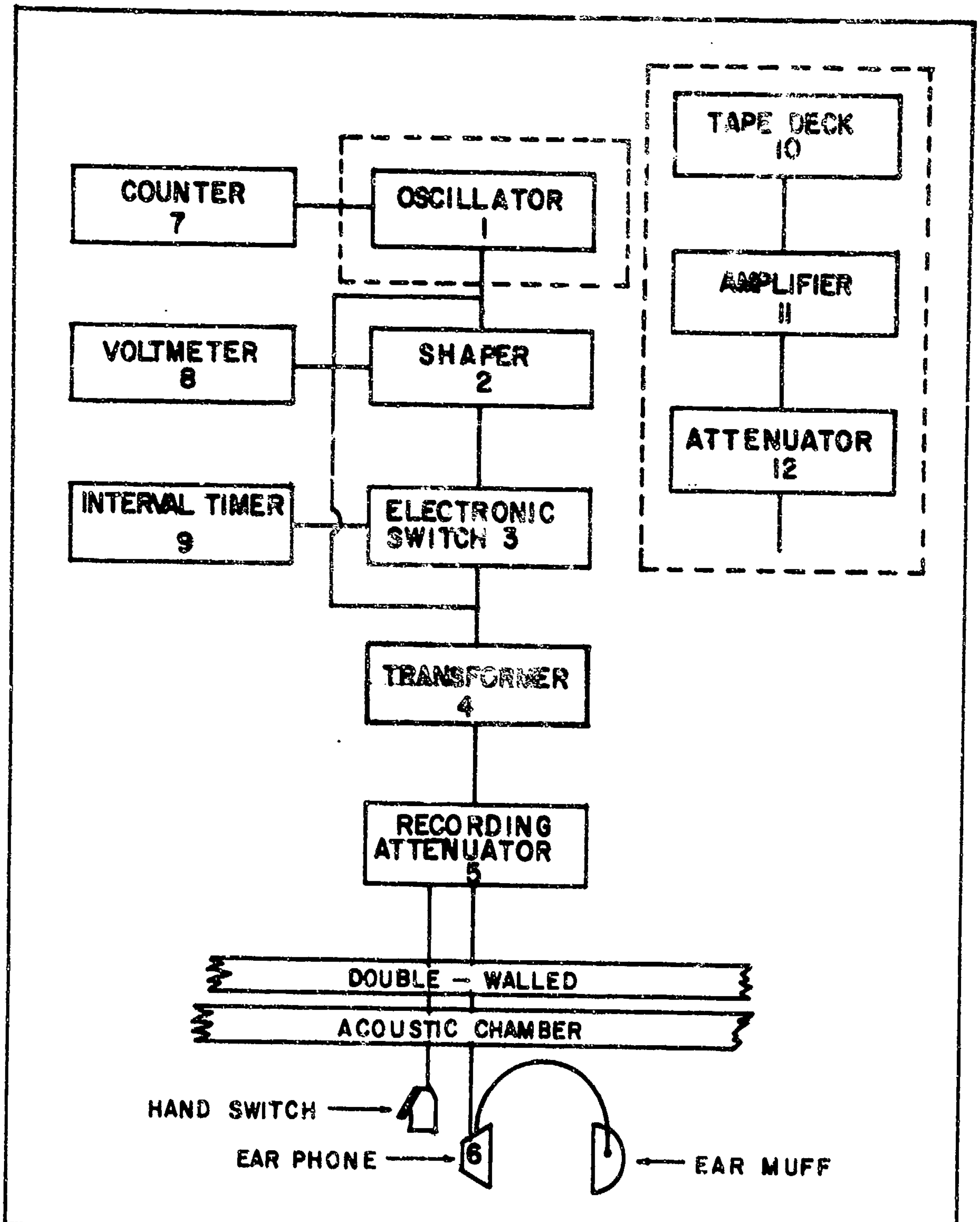

Figure 2. Instrumentation used to measure the ears' hearing thresholds, and the detection thresholds for the test sounds. 1, Hewlett-Packard model 241-A oscillator. 2, General Radio model 1925 multifilter. 3, Grason-Stadler model 829E electronic switch. 4, Grason-Stadler model E10589A matching transformer. 5, Grason-Stadler model E3262A recording attenuator. 6, Sennheiser model HD424 earphone. 7, Computer Measurements Co. model 608 frequency counter. 8, Hewlett-Packard model 3400A voltmeter. 9, Grason-Stadler model 471-1 interval timer. 10, Sony model TC-366-4 tape recorder. 11, Bogen model CHS-100 amplifier. 12, Hewlett-Packard model 350D decade attenuator.

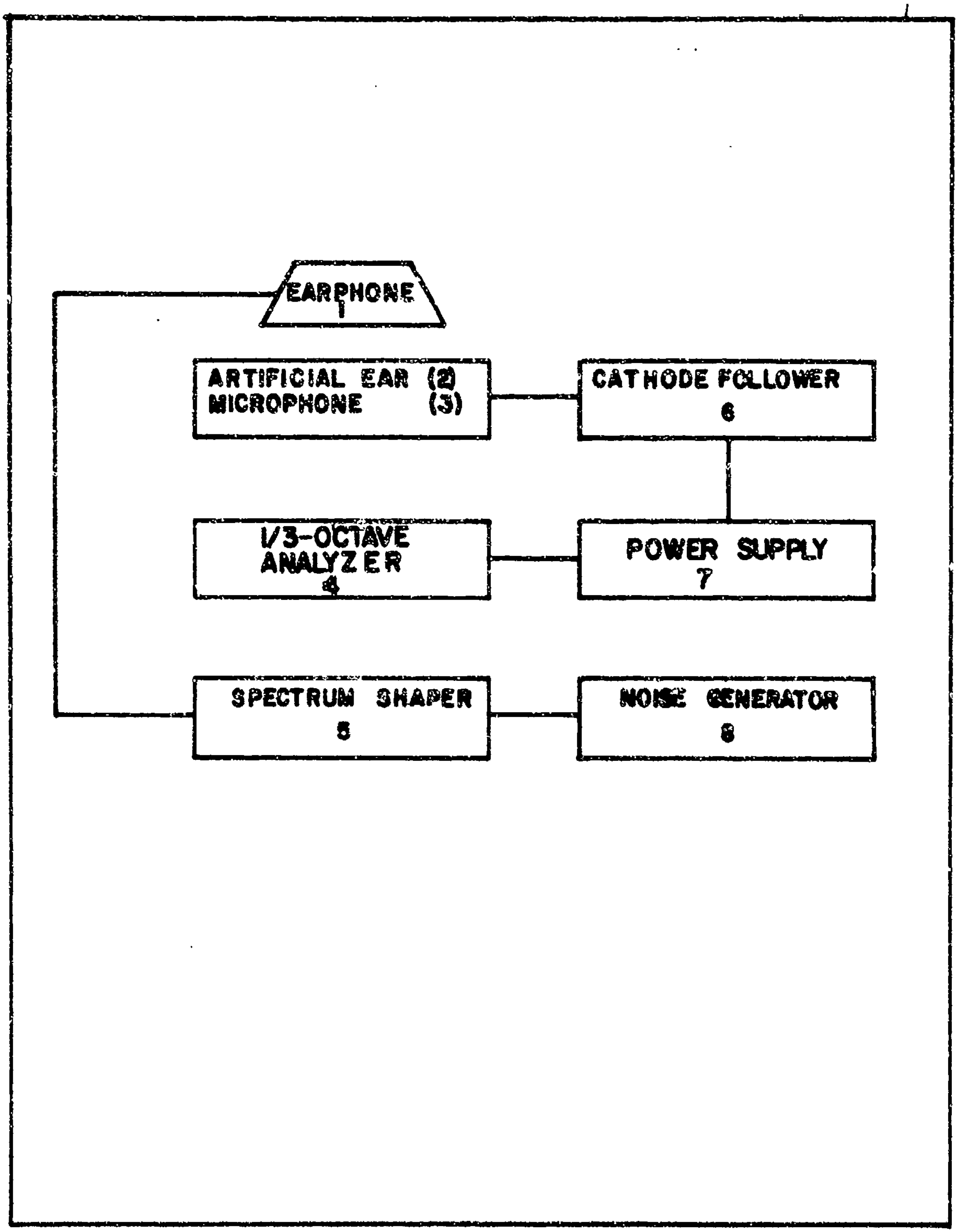

Figure 3. Instrumentation used to establish the earphone compensation to provide a flat frequency response from 100 to 15,000 Hz. 1, Sennheiser model HD 414 earphone. 2, Bruel & Kjaer type 4153 artificial ear. 3, Bruel & Kjaer type 4134 microphone. 4, Bruel & Kjaer type 3347 analyzer. 5, General Radio model 1925 multifilter. 6, Bruel & Kjaer type 2615 cathode follower. 7, Bruel & Kjaer type 2801 power supply. 8, Bruel & Kjaer type 1402 noise generator.

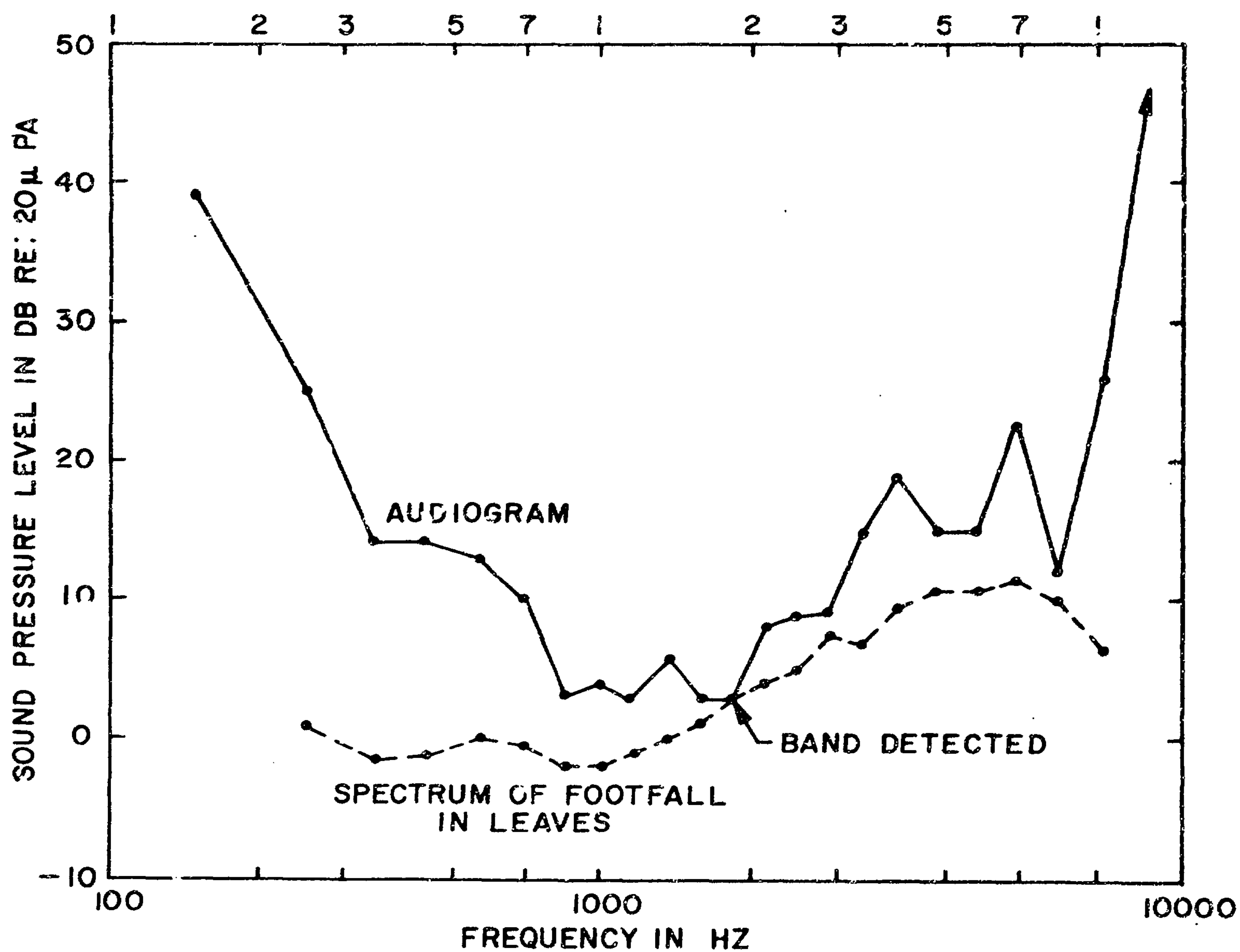

Figure 4. Juxtaposition of a hearing-threshold plot with a sound spectrum. The two curves meet in band 13, so it was assumed that this band would be the first band this particular ear detected.

RESULTS AND DISCUSSION

Spectra of the Test Sounds

The spectra of the test sounds are presented in Figures 5 through 15. The upper spectrum for each sound represents the maximum pressure present in each band when integrated for 200 msec. The lower spectrum is the maximum pressure present during any 20-msec period. As would be expected, the sounds with a more nearly continuous character, such as a footfall in grass (Figure 5), show the greatest separation between spectra. The maximum separation observed with the sounds tested was about 8 dB; 10 dB would, of course, have been the theoretical maximum. For sounds that have a more transient, or click-like, character, such as inserting the M16 magazine (Figure 6), the separation between the two lines is very slight. Most of the energy in these sounds arrived in a very short time, and integration did not increase the level very much.

The spectral shapes are also interesting. Some sounds, such as a footfall in gravel (Figure 7), show maximum energy in the low-frequency region. Others, such as the sound made when trimming with a machete (Figure 8) or a footfall in grass (Figure 5), have much more even energy distribution across the spectrum. Still others, such as a footfall on leaves (Figure 5) or the Springfield rifle bolt (Figure 8), have most of their energy in the high-frequency region. To round out the range of possibilities, some sounds, such as inserting the AK47 magazine (Figure 9), had most of their energy concentrated in the middle-frequency region. Insofar as these sounds represent those that soldiers need to detect in the field, it would appear that good hearing sensitivity in all frequency regions would be advantageous. Another point that might be noted about spectral shapes is that, even for the most peaked distributions, the difference between regions of maximum and minimum energy was only about 20 dB. This implies that hearing loss in the form of a notch (narrow frequency region) would not impair detectability greatly, even for those sounds with peaked energy distributions. As soon as the intensity of the sound increased slightly, the remaining hearing sensitivity would detect some portion of the sound's energy.

Prediction of Detection

The correlation coefficients for the predicted and actual detection levels ranged from .89 to .98, with a mean for the 24 sounds of .94. Thus about 88.4 percent of the variance was accounted for. The standard error of estimate (deviation from the regression line) ranged from 3.0 to 5.1 dB, and averaged only 4.1 dB. This is quite small when one considers that the standard deviation for test-retest audiometric data is normally on the order of 5 dB. It can be concluded that the model predicts monaural detectability in quiet exceedingly well, and that additional refinement could add almost nothing to its predictive capacity.

Applications to Operational Situations

The logical questions that arise at this point are how we might expect normal and impaired ears to differ in their ability to detect sounds, and how much hearing loss affects performance in operational situations. We hasten to interject at this point that the final answer to these questions is still in the future; however, the present data, when coupled with what is now known about the hearing of soldiers in the combat arms, and the environments in which they might function, do result in some interesting conclusions.

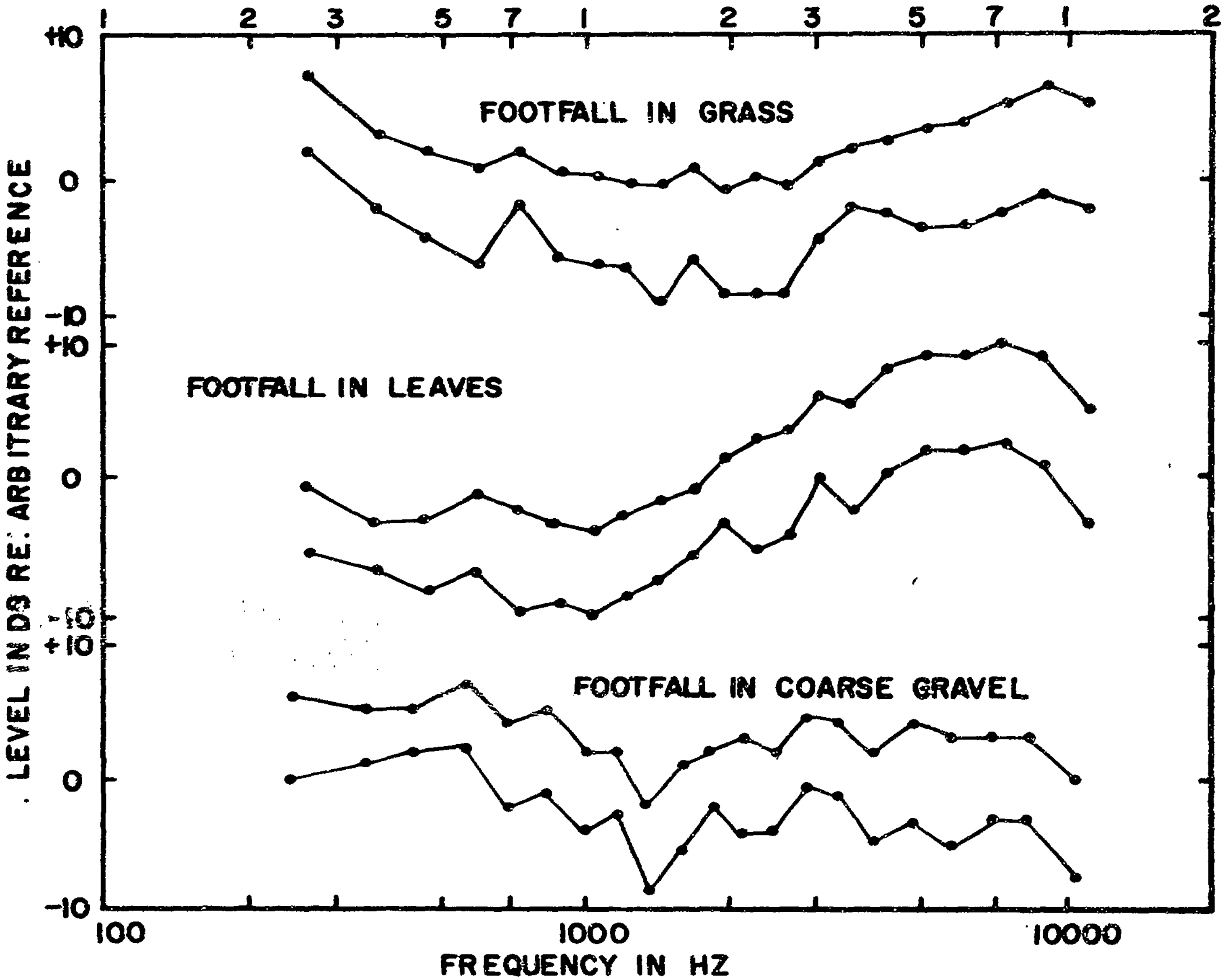

Figure 5. Spectra of three test sounds: A footfall in grass, leaves, and coarse gravel. Upper curve represents the maximum pressure present in each band when integrated for 200 msec. Lower curve shows maximum pressure during any 20-msec period.

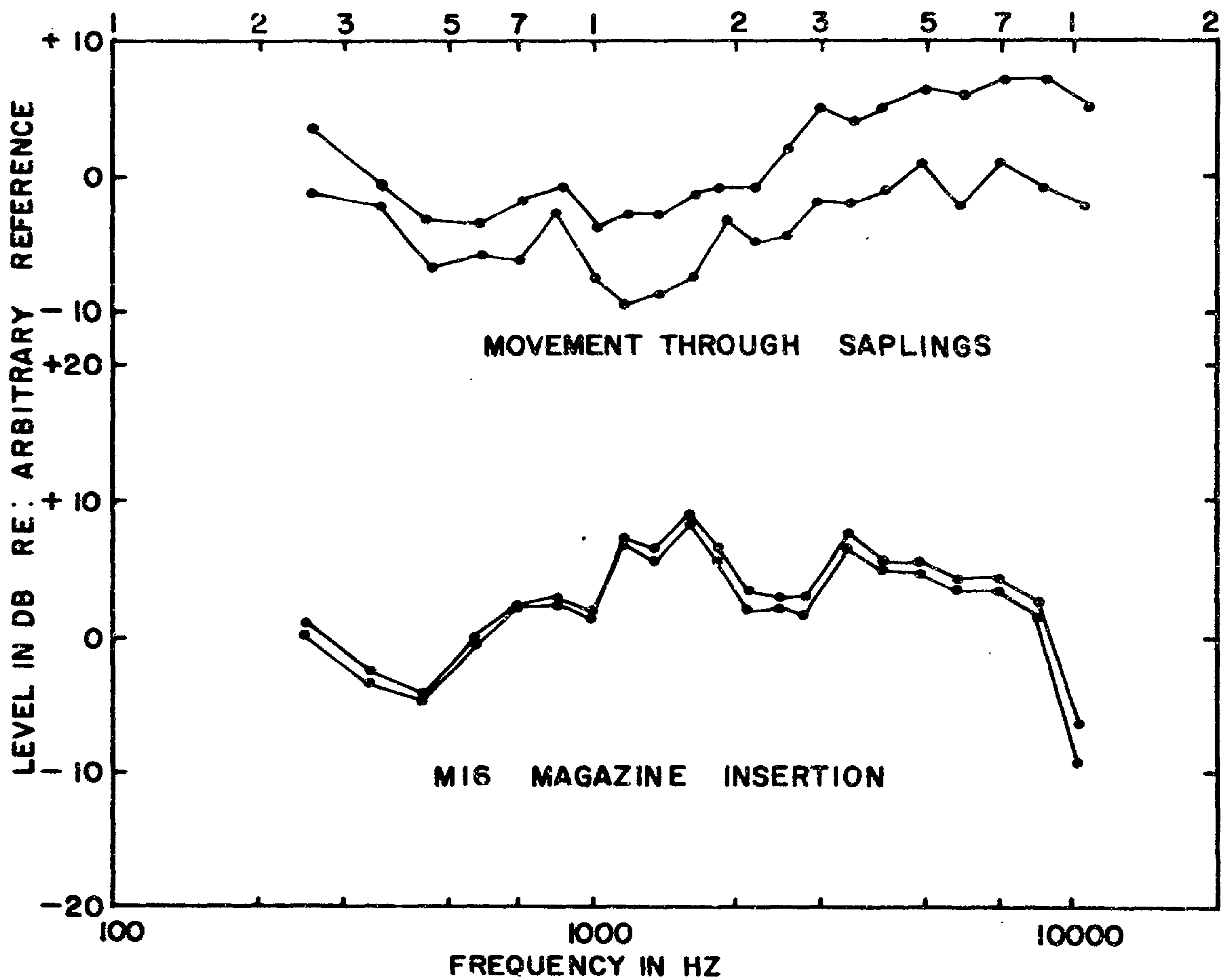

Figure 6. Spectra of two test sounds: Movement through saplings, and insertion of M16 rifle magazine.

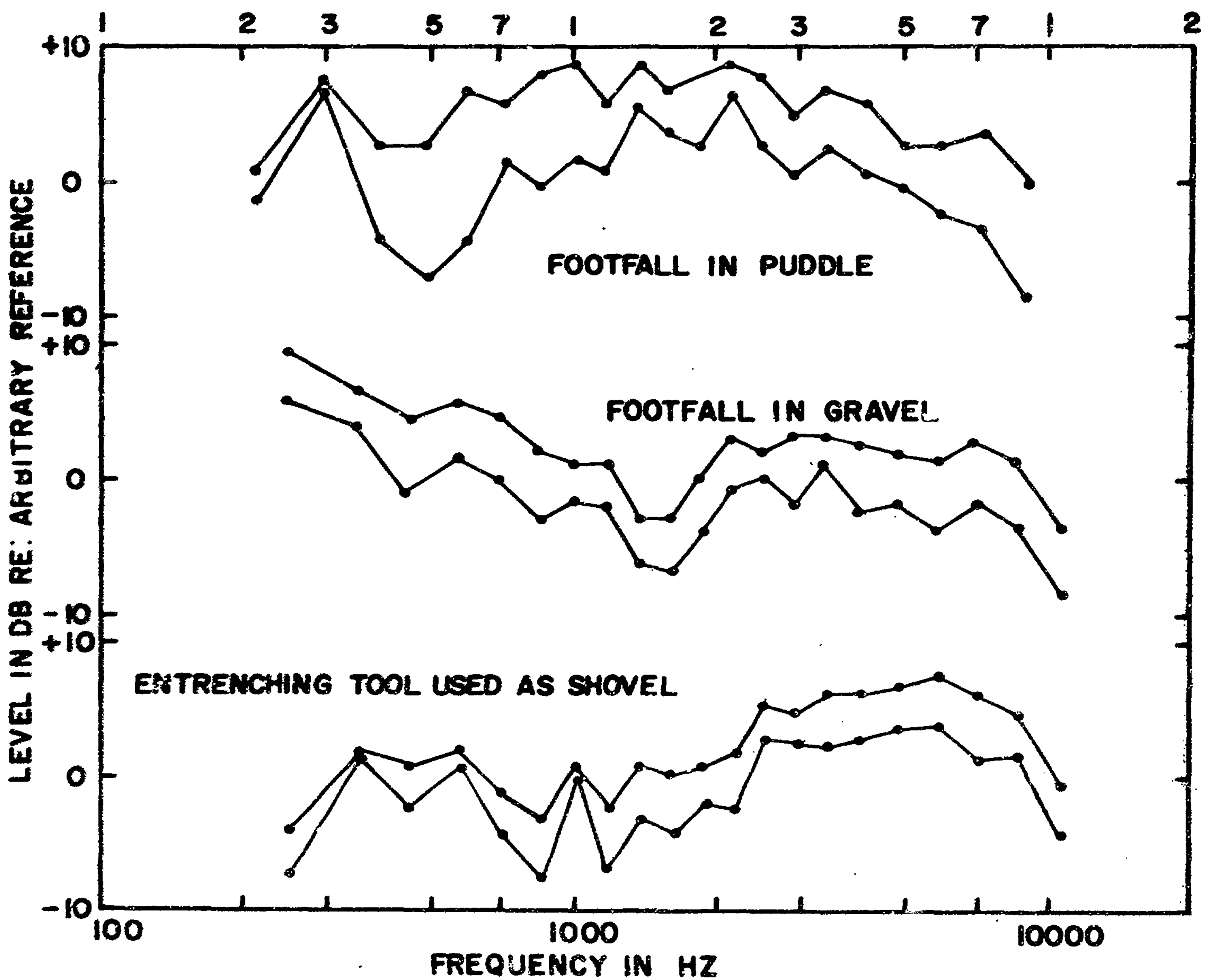

Figure 7. Spectra of three test sounds: Footfall in a puddle and on gravel, and an entrenching tool used as a shovel.

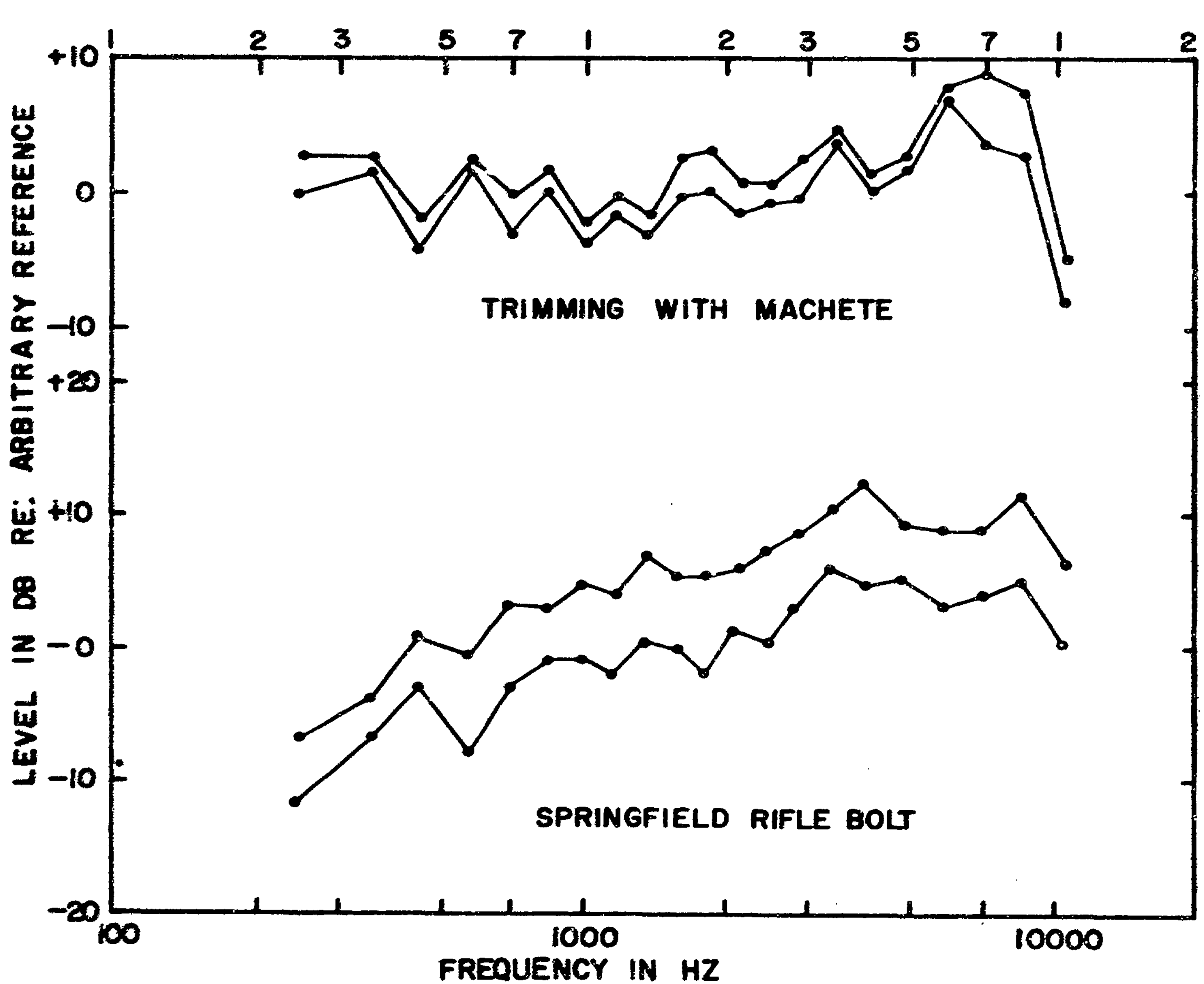

Figure 8. Spectra of two test sounds: Trimming limbs with a machete, and operating the bolt of a Springfield rifle.

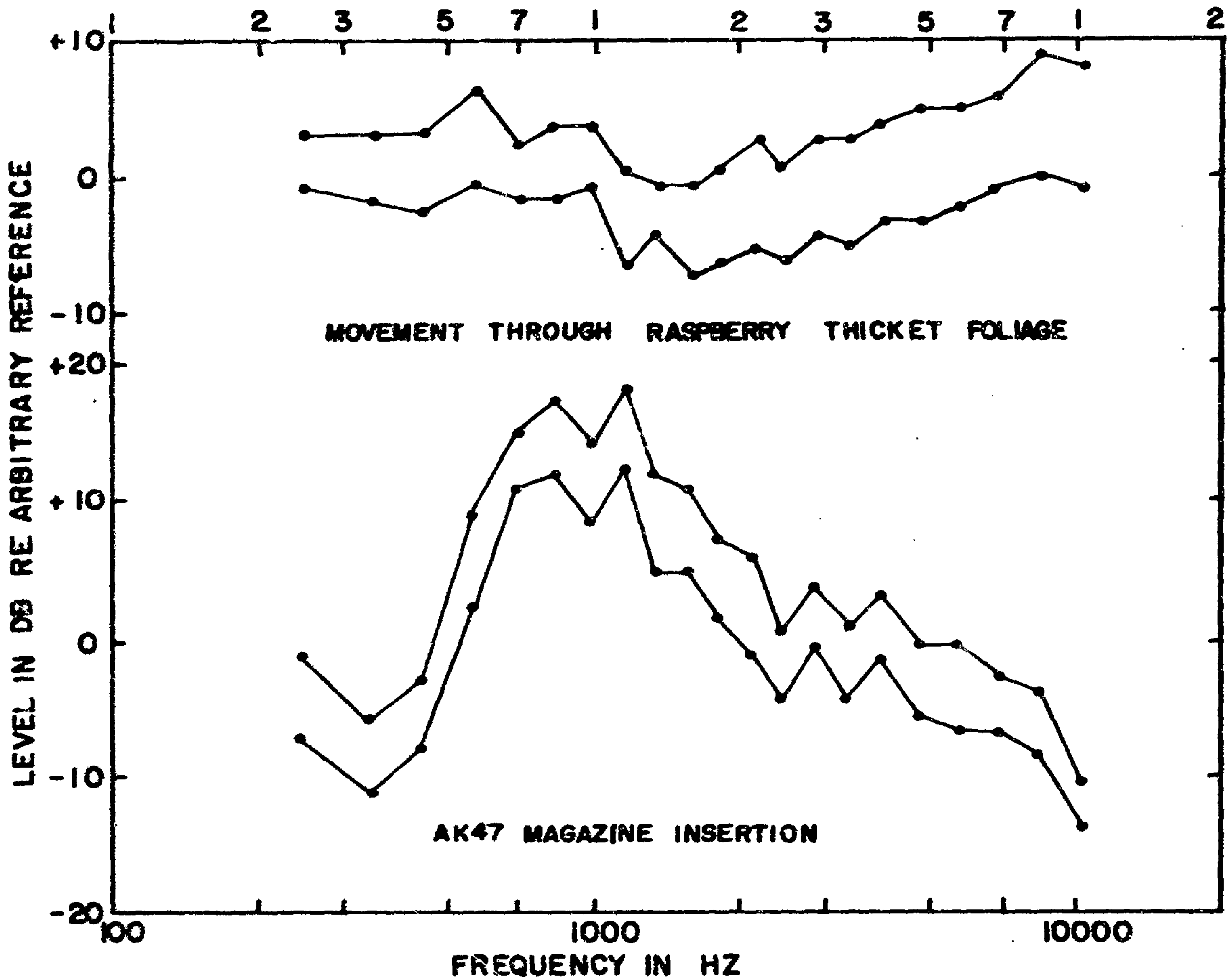

Figure 9. Spectra of two test sounds: Movement through a raspberry thicket, and insertion of an AK47 rifle magazine under reverberant conditions.

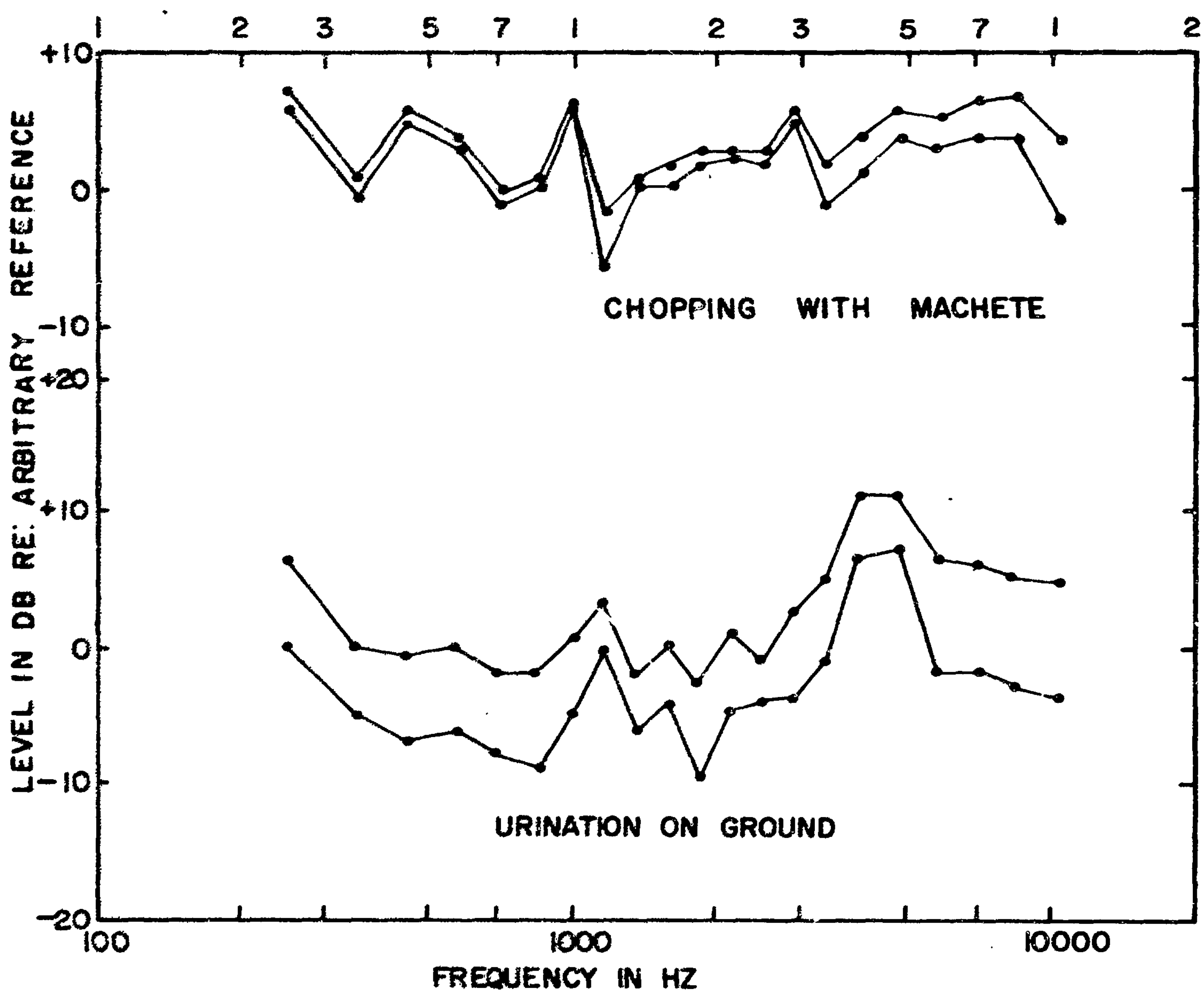

Figure 10. Spectra of two test sounds: Chopping with a machete, and urination on the ground.

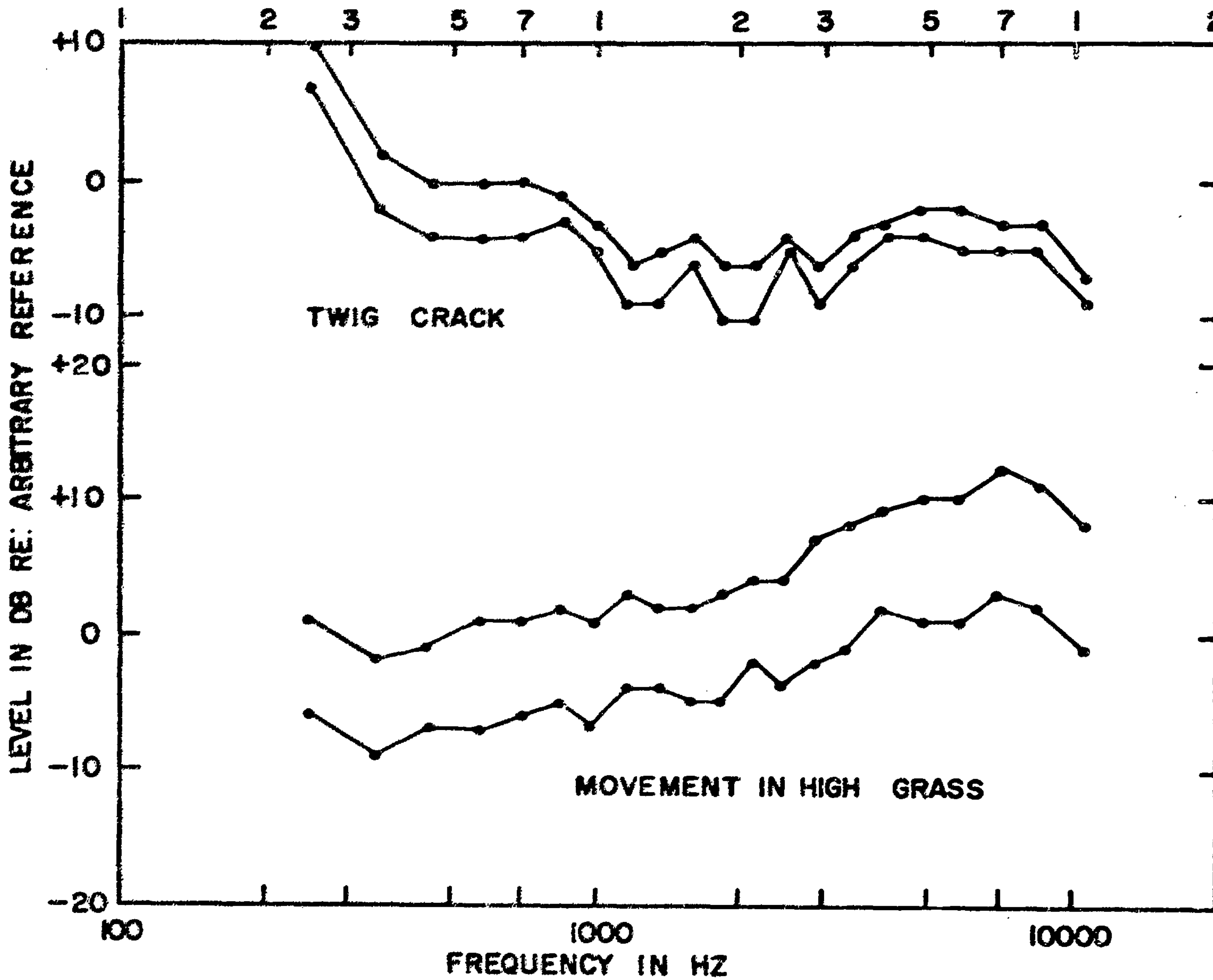

Figure 11. Spectra of two test sounds: Footfall on twigs, and movement through high grass.

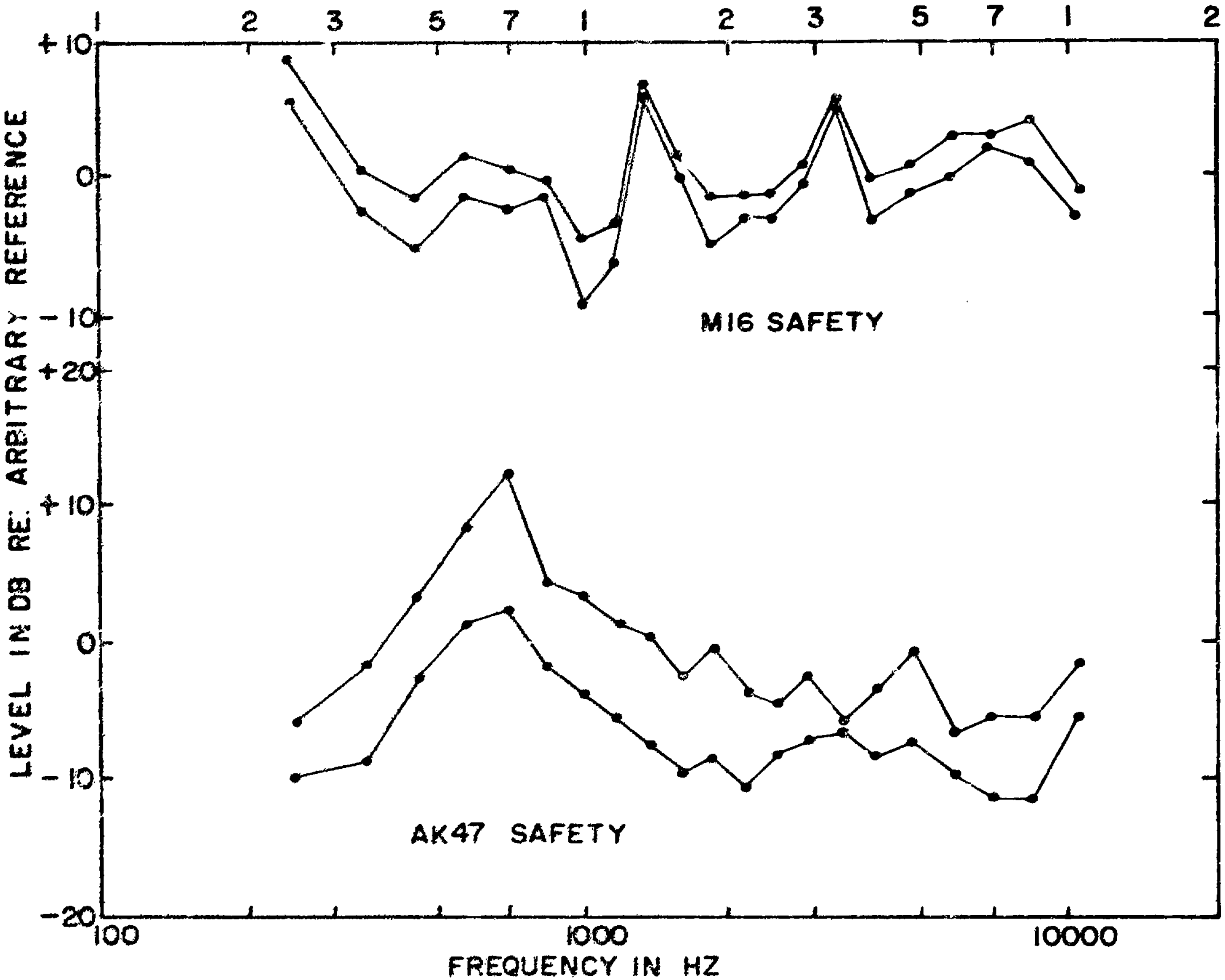

Figure 12. Spectra of two test sounds: M16 rifle safety being released, and AK47 rifle safety being released.

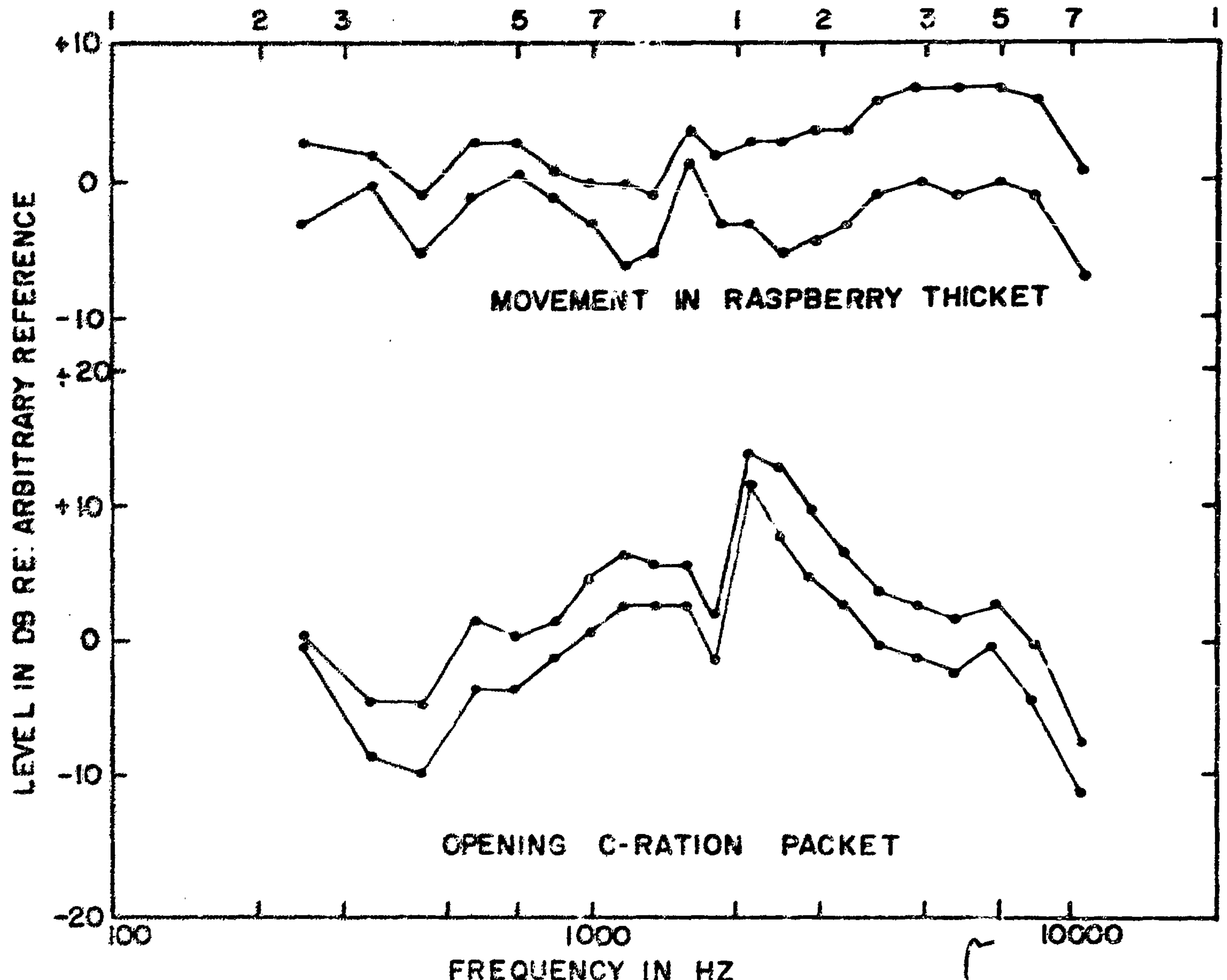

Figure 13. Spectra of two test sounds: Movement through a raspberry thicket, and a C-ration pack being torn open.

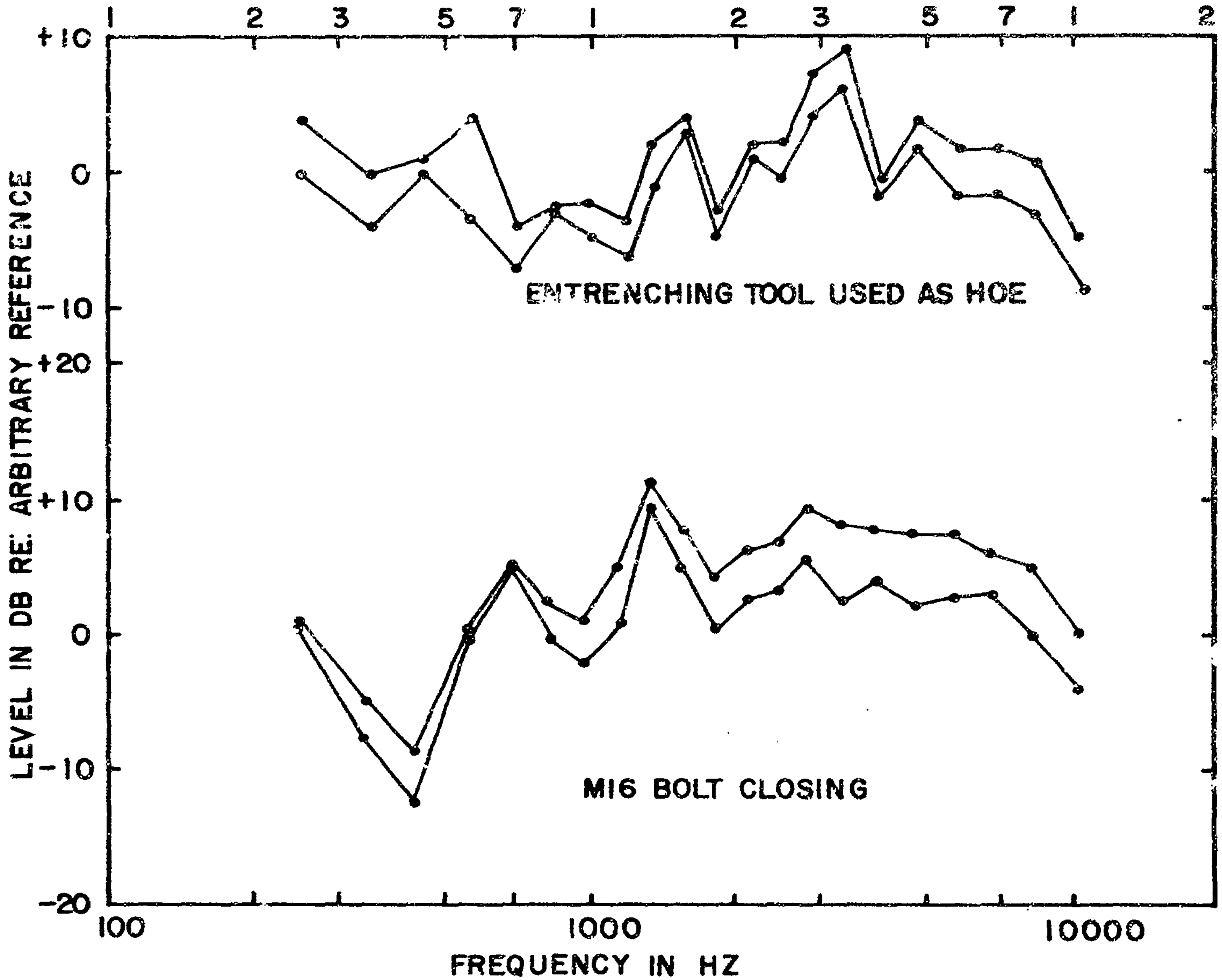

Figure 14. Spectra of two test sounds: An entrenching tool being used as a hoe, and an M16 rifle bolt being operated.

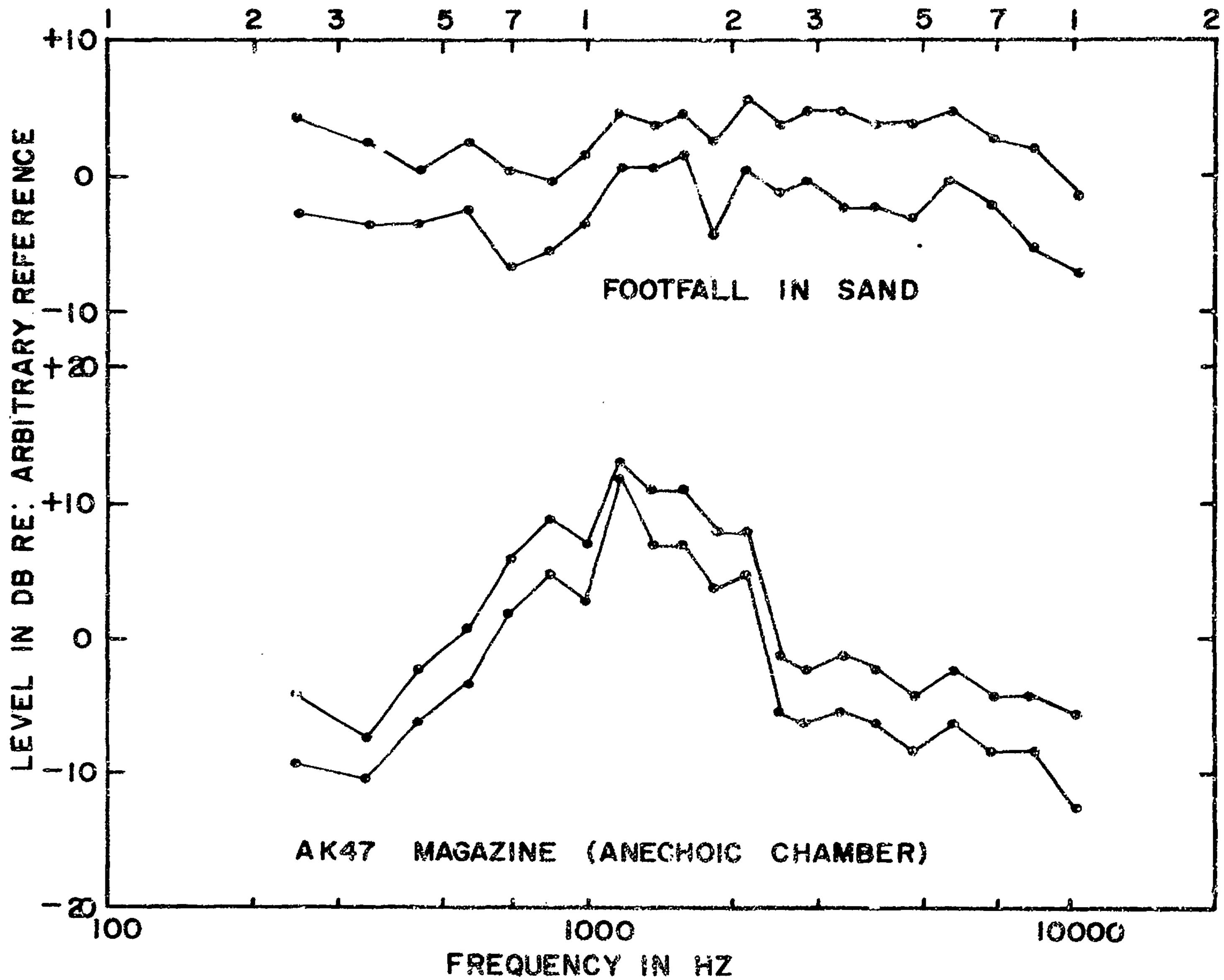

Figure 15. Spectra of two test sounds: A footfall in sand, and an AK47 rifle magazine being inserted under anechoic conditions.

We are fortunate in having some excellent data on the hearing levels of soldiers in the combat arms: armor, infantry and artillery (8). In this cross-sectional survey, hearing levels of 3000 soldiers were measured following varying periods of service, and the average hearing levels following varying periods of service were derived. Some of these data, converted to absolute sound-pressure level, are presented in the upper three curves of Figure 16. The upper curve (worst hearing) is that of the average man with 17.5 to 22.4 years of service; the center curve represents the weighted average for all ears in these combat arms; and the lower curve represents the average for the youngest ears (1.5 - 2.4 years of service). The bottom curve in Figure 16 is the standard curve for audiometric zero, i.e., the hearing sensitivity expected of a young, normal ear.

These four curves were then used with the test-sound spectra to derive predictions about detection. The young, normal ear would have detected sounds much more readily than the oldest Army ears—on the average, at intensities about 16 dB lower (range: 12 - 24 dB). The differences were, of course, smaller for the younger ears where the hearing losses were less severe. Given the relatively large hearing losses at the higher frequencies in older ears, larger differences in detection might have been expected. The reason they were not larger is that most of the detections were made on the basis of sound energy in the 1000-Hz frequency region, where the ears did not differ much in sensitivity. Stated another way, even the sound spectra with the most high-frequency energy had too little of it for the ears with relatively good high-frequency sensitivity to detect those frequencies before the energy at the lower frequencies crossed the threshold. For two reasons, which will be discussed in the next sections, it would be premature to draw any conclusions from these data about how hearing loss affects performance.

These differences in detection could have considerable practical significance, except for one thing that was revealed by subsequent analysis. Namely, these detections were measured under very quiet listening conditions inside a specially designed acoustic test chamber. If a war were ever fought in such a chamber, the data would apply with only minor qualifications. However, the real world, even at its quietest, has considerable noise present. If a sound is to be detected, then the energy present must not only exceed the absolute sensitivity of the auditory system, but it must also exceed the ambient noise level, or else it will be masked by the noise. Examples of typical outdoor ambient-background-noise spectra are presented in Figure 17 (2). For frequencies in the mid-range and below, the jungle is quietest, so long as there are no insect or animal sounds. If insect sounds are present, there is a dramatic increase in the amount of high-frequency energy, so that the spectral curve rises at about 9 dB/octave between 700 Hz and 10 kHz. The background-noise spectrum for rural France (late in the evening without machinery sounds) is almost the reverse of the previous curve, showing a spectrum that declines with increasing frequency.

To estimate the effect of these background noises on detection, the curves in Figure 16 (representing the hearing of typical Army ears, as well as young, normal ears) were combined with the background noises; predictions of detectability were then redetermined for the set of 24 sounds used in these experiments. From these data, it is apparent that the background noise exerts an overwhelming effect on detection, and that the differences between ears are consequently much smaller than when testing was done in the quiet. In the case of jungle noise with insects and animals present, the predicted differences between the best and worst ears averaged only 0.3 dB! In this case, almost all of the predicted detections occurred because of energy in the low-frequency region, where the ears were not very different in their sensitivities. The low-frequency masking noise also acted to equalize them by negating the superior sensitivity of the best ears.

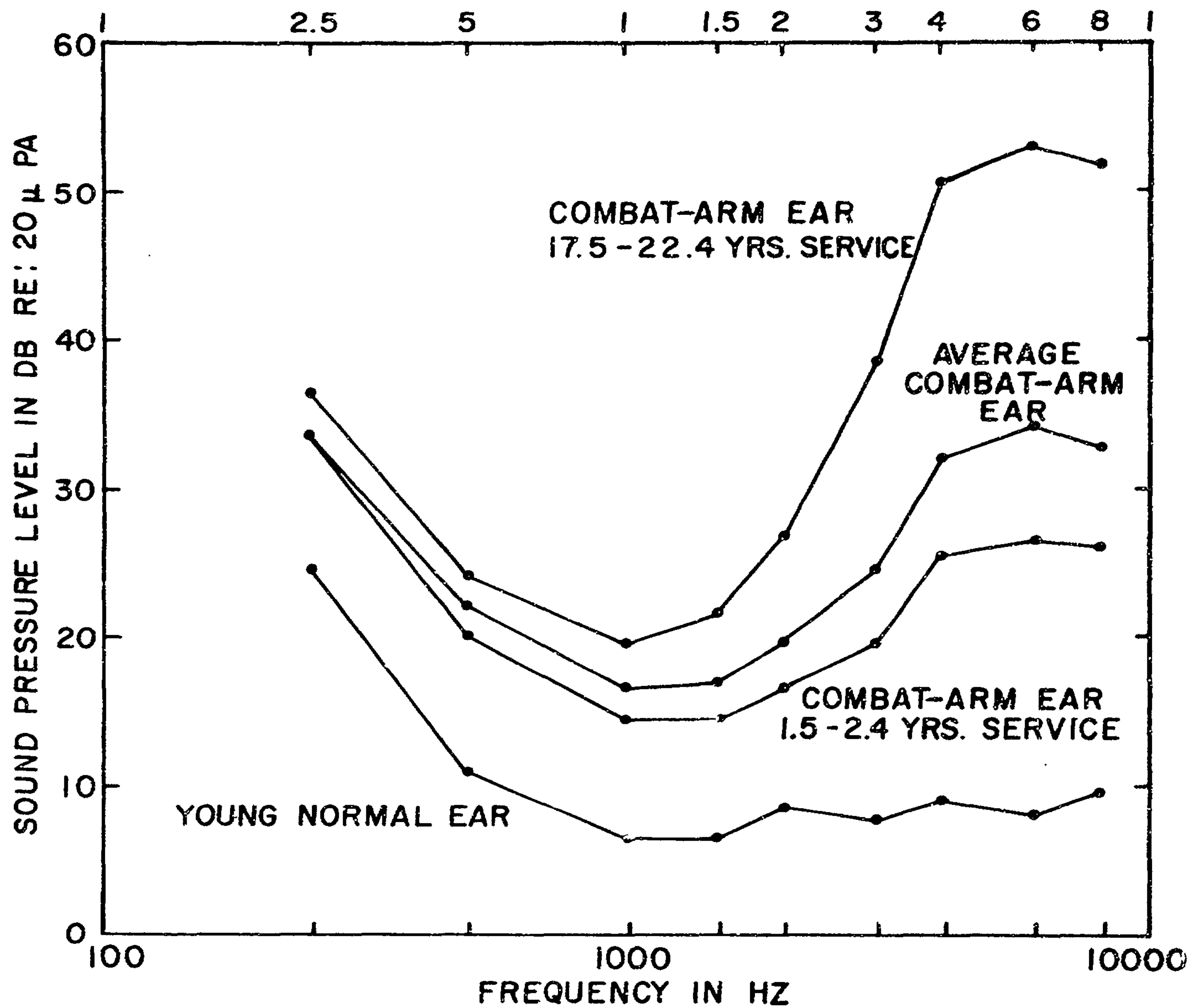

Figure 16. Hearing-threshold curves showing typical audiometric zero hearing levels for various lengths of Army service. Top curve: 17.5-22.4 years service. Second curve: weighted average for all ears in the three combat arms surveyed. Third curve: 1.5-2.4 years service. Bottom curve: audiometric zero. From (8).

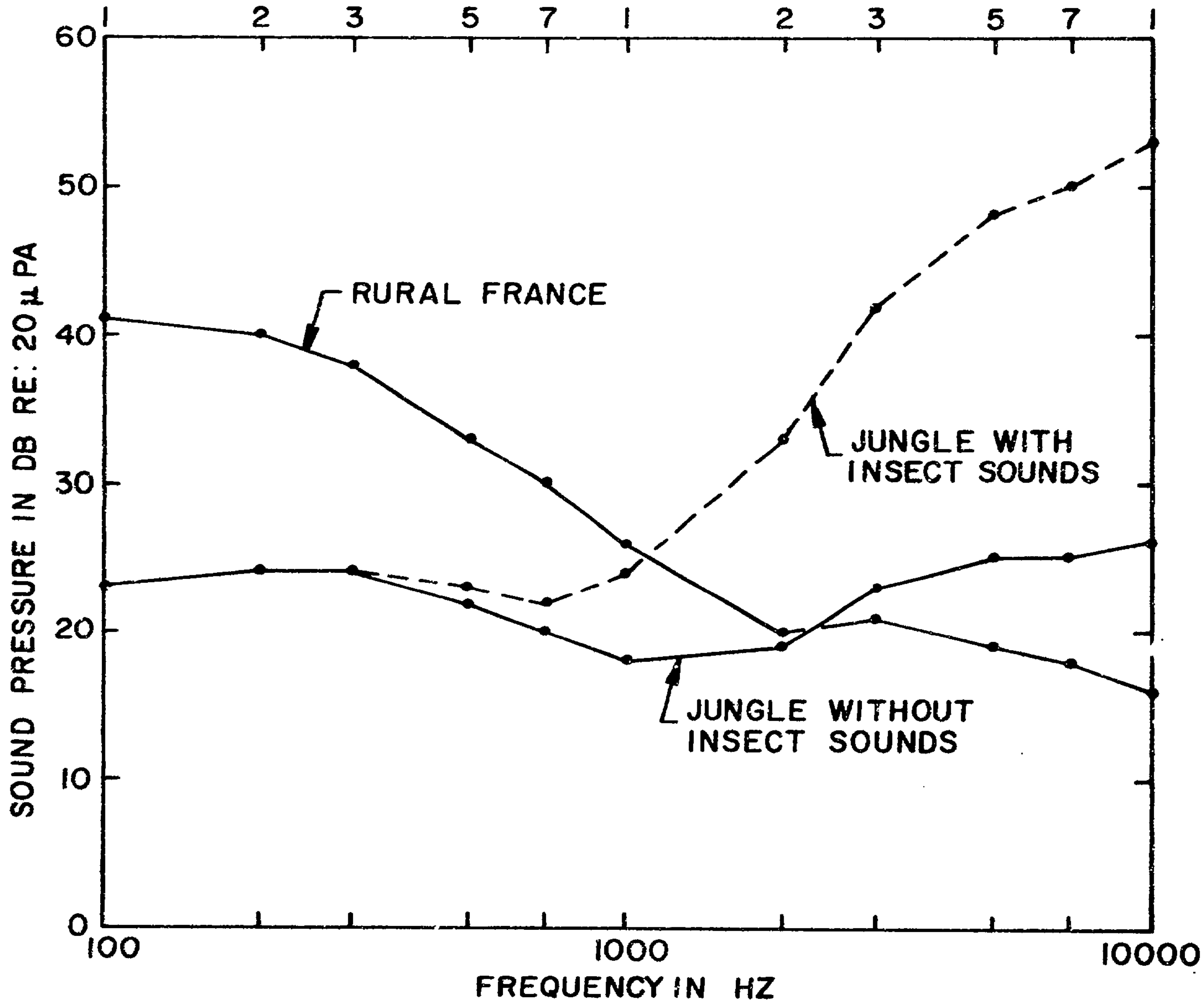

Figure 17. Examples of typical outdoor ambient-background-noise spectra. From (2).

The differences were not much greater for the jungle without insect noises; the predicted difference between the youngest and oldest Army ears was only 2.7 dB. In the spectrum present in rural France, however, the low-frequency content of the background noise was high enough that the detections tended to depend on higher-frequency energy. In this case, the ears that had retained better high-frequency sensitivity were somewhat better able to detect. The young, normal ear did better than the old Army ear by 7.8 dB on the average, and the youngest combat-arm ear did about 3.9 dB better than the oldest combat-arm ear.

These differences, while not negligible, are nonetheless rather small and, taken alone, would not seem to justify much concern for preserving hearing in our combat troops. In our opinion, however, this would be both a premature and an exceedingly dangerous conclusion to draw from these data. The specific performance these experiments tested was the ability to detect the presence of some sound exceeding background and/or physiological noise levels. At the outset, this type of performance was defined as detection, and differentiated from identification. Only as the intensity of a sound increases 20 dB or more beyond the detection level does the sound assume a quality where it sounds like something. In assessing performance in the field, it is this second level of analysis, identification, that is most important. At the moment, however, it is not possible to say just how much the intensity of sounds of the type we are concerned with must be increased above detection levels before identification can occur. Some preliminary data also suggest that this amount may be very different for normal ears and ears that have lost some sensitivity. Indeed, the most common complaint of an individual suffering from a hearing loss is not that he hears nothing, but that he cannot make sense out of what he does hear. The loss that an ear suffers appears, at a practical level, to be not so much one of sensitivity as one of analytical capability. This is clearly an important issue that needs to be settled before any conclusion is drawn about hearing sensitivity and performance in the field.

There are also a number of additional points that subsequent research should focus on, in coming to grips with the importance of auditory input in operational situations. Signal-detection theory, for example, suggests that a number of variables enter into the detection and identification process. Among them are the statistical distributions of both physiological noise and background noises. We do not know what these distributions are for the types of sounds encountered in the field. Furthermore, the consequences of detecting a sound are also known to influence the likelihood of making a correct detection, as well as the likelihood of making a false alarm; if announcing a detection has no negative consequences, the detections will be at their earliest, but the false alarms will also be greatest, and vice versa. The answers to these and other questions in this area are likely to have considerable significance for the Army in a variety of settings; therefore, we are conducting additional research to clarify the important interactions between the physical and psychological variables that operate when the human ear is used to detect and analyze combat-relevant sounds.

SUMMARY AND CONCLUSIONS

The U.S. Army Human Engineering Laboratory has initiated a comprehensive program of research to examine the hearing requirements of soldiers in a variety of operational contexts, and to determine how hearing loss affects performance. The initial focus of this program is on the aural detection and identification of combat-relevant sounds, which might enable soldiers to determine the presence and intentions of enemy personnel. The initial experiments reported here examine the factors involved in detecting sounds of personnel movement and personnel activity. One of the present effort's most important contributions has been the development of a

detection model which incorporates the ear's analysis of incoming energy into critical bands of frequencies, and its integration of energy arriving during a period of 200 msec. Based on these theoretical considerations, a unique computer-based analysis procedure was developed, which was used to predict the critical band(s) of primary importance in detecting representative combat-relevant sounds.

Experiments were conducted using 20 ears representing differing degrees of threshold sensitivity, and encompassing the range usually observed for Army ears. Detection thresholds were obtained for tonal stimuli at the center frequencies of critical bands, for both 200- and 20-msec duration tones. By juxtaposing the 200-msec-tone audiograms with the spectral plots for the test sounds, the listening level at which detection would occur could be predicted. The mean correlation coefficient between predicted and actual detection level was .94, which suggests that, considering known sources of variance in threshold testing, the detection model worked exceedingly well.

The results were used to predict sound-detection thresholds for representative Army ears, based on a recent survey of hearing sensitivity among combat-arms personnel. This analysis showed that, in the quiet, predicted differences between older Army ears and young, normal ears would average 16 dB. However, when detections were predicted for sounds accompanied by typical background noises, the background noise's masking effect overshadowed differences between ears. These results apply to simply detecting the presence of sound. The argument was advanced that identifying sounds is more important for predicting performance in the Army context.

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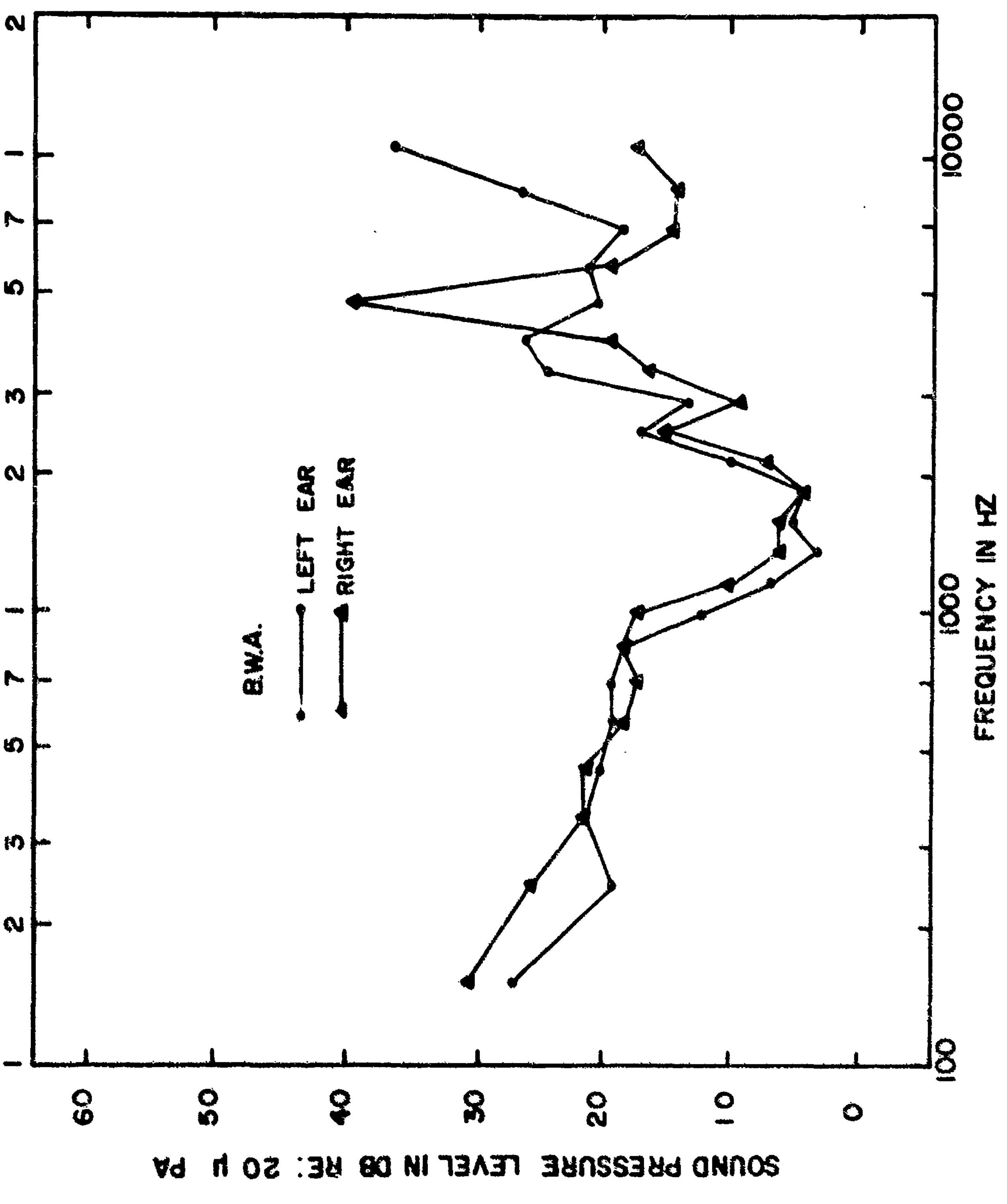
APPENDIX

AUDIOGRAMS FOR THE 20 EARS USED IN THIS STUDY


B.W.A.
LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
SOUND PRESSURE LEVEL IN DB RE: 20 μ PA
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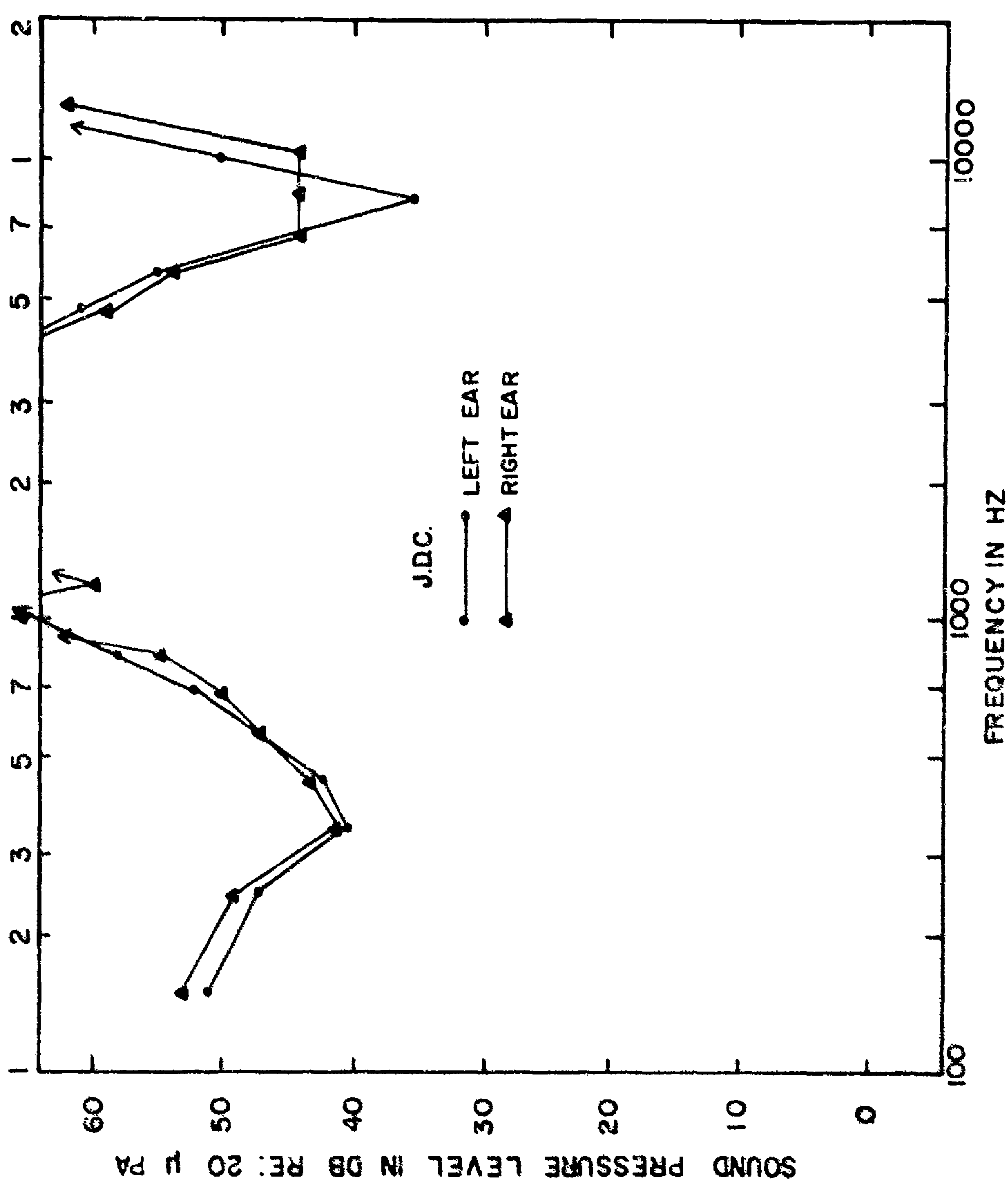
J.D.C.
LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
SOUND PRESSURE LEVEL IN DB RE: 20 μ PA
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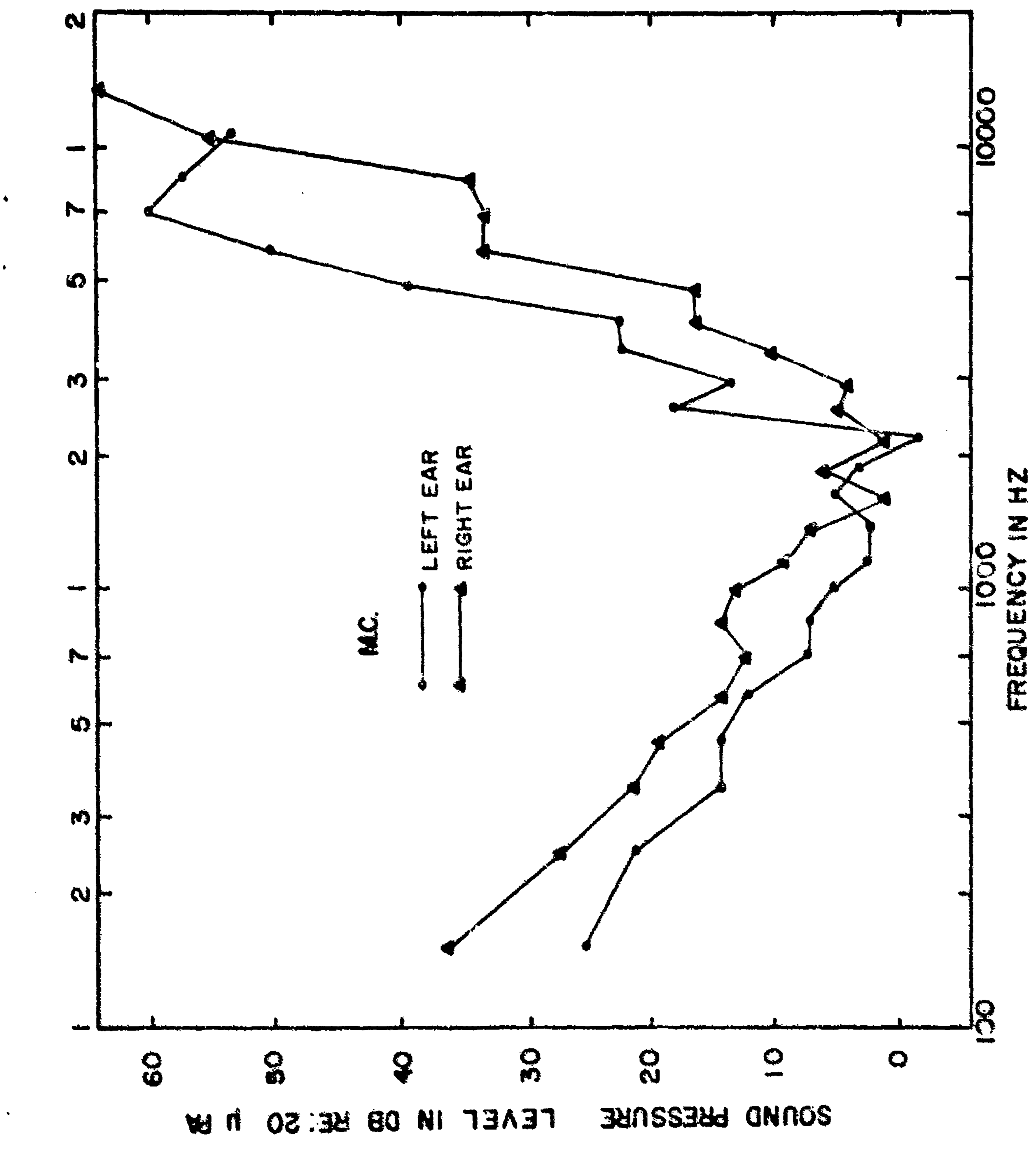
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LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
SOUND PRESSURE LEVEL IN DB RE: 20 µ PA
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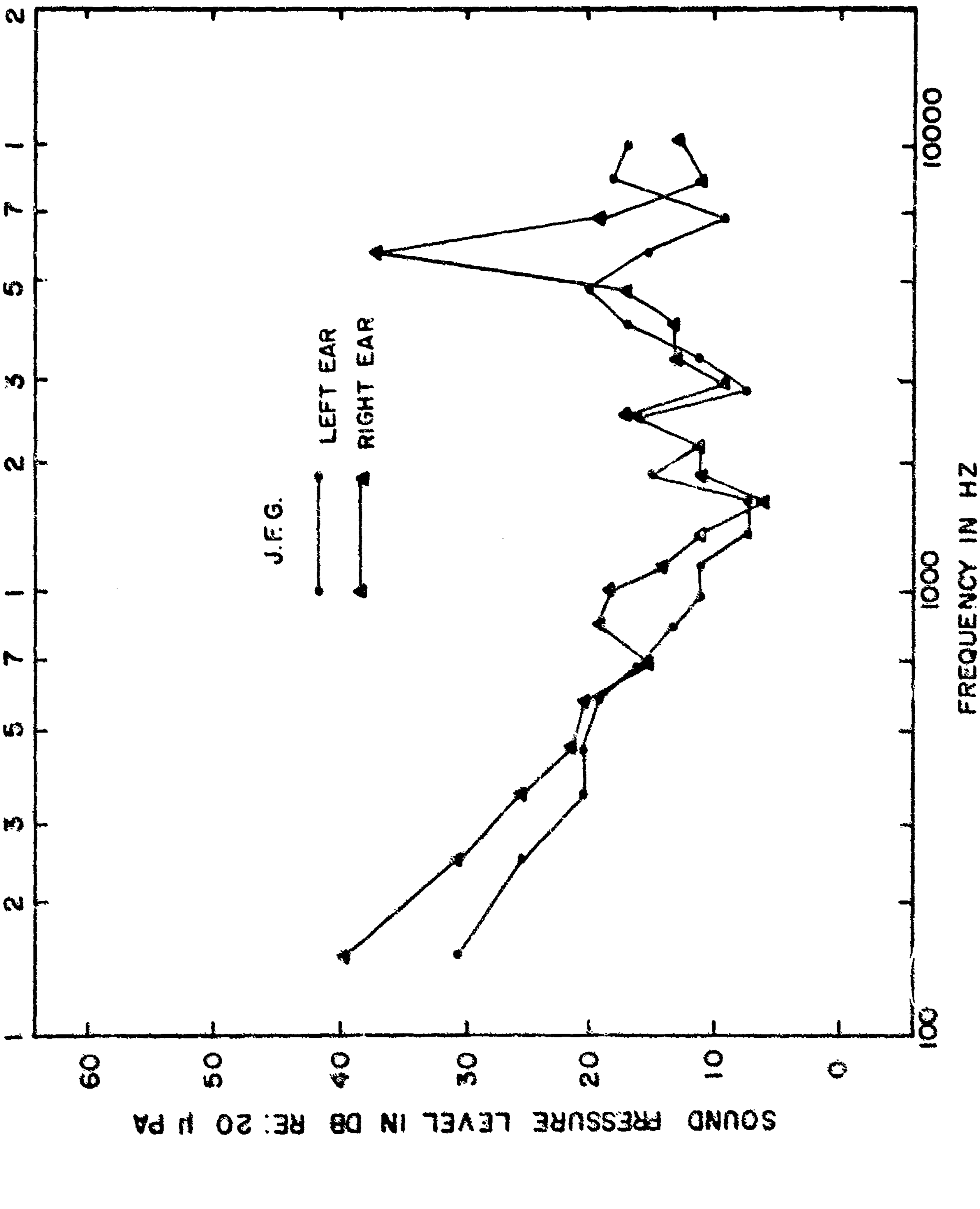
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RIGHT EAR
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SOUND PRESSURE LEVEL IN DB RE: 20 μ PA
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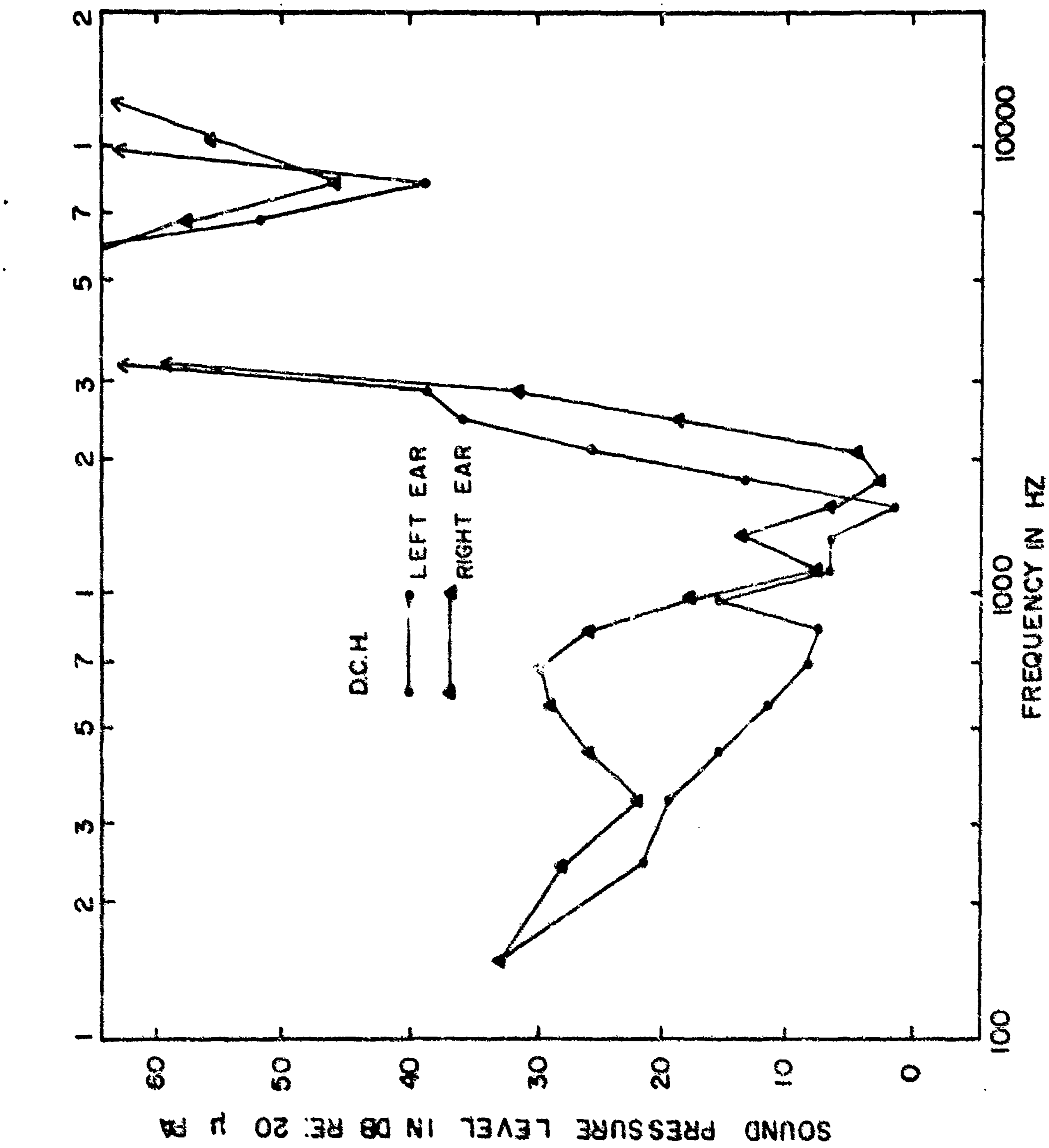
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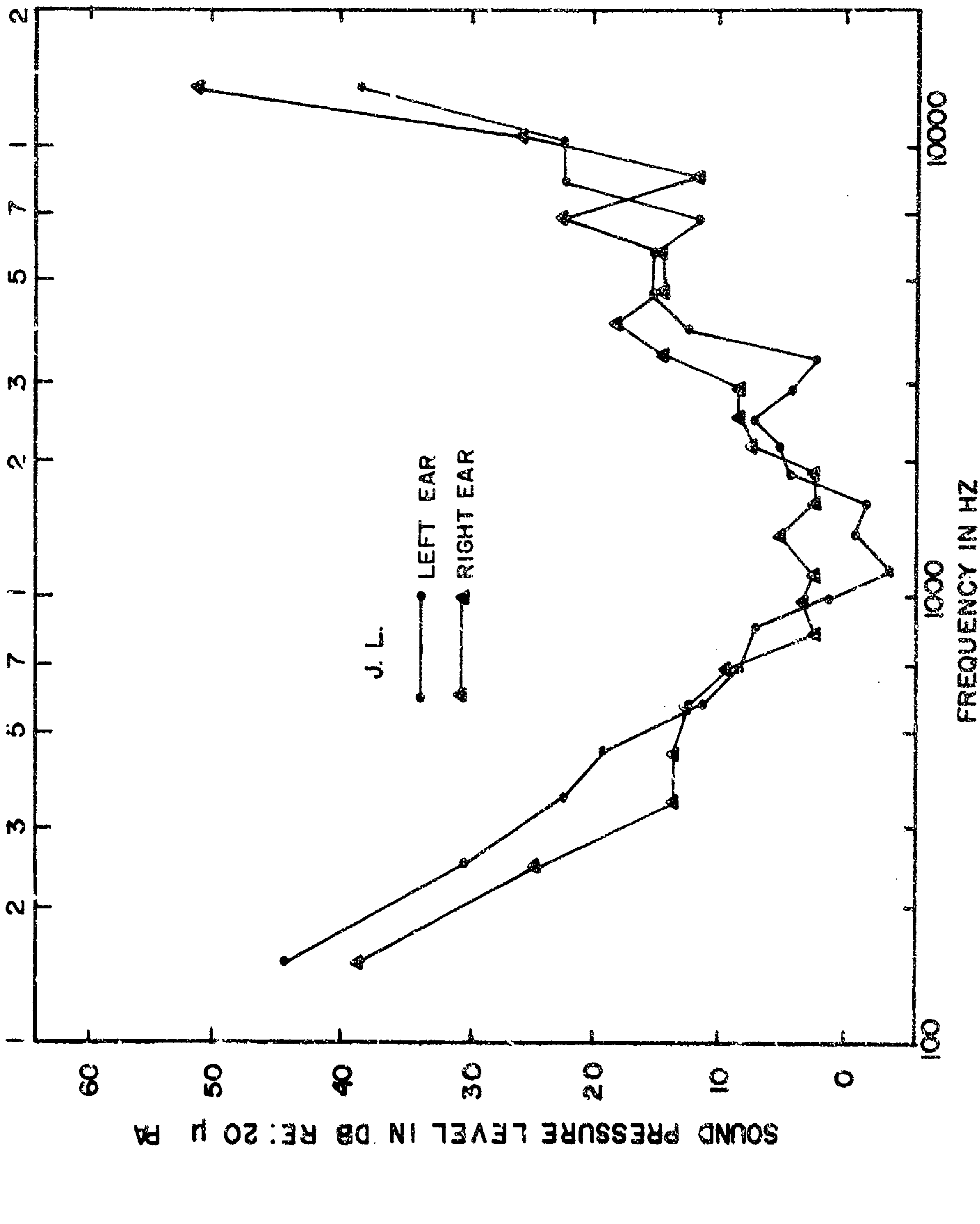
J. L.
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RIGHT EAR
FREQUENCY IN HZ
SOUND PRESSURE LEVEL IN DB RE: 20 μ PA
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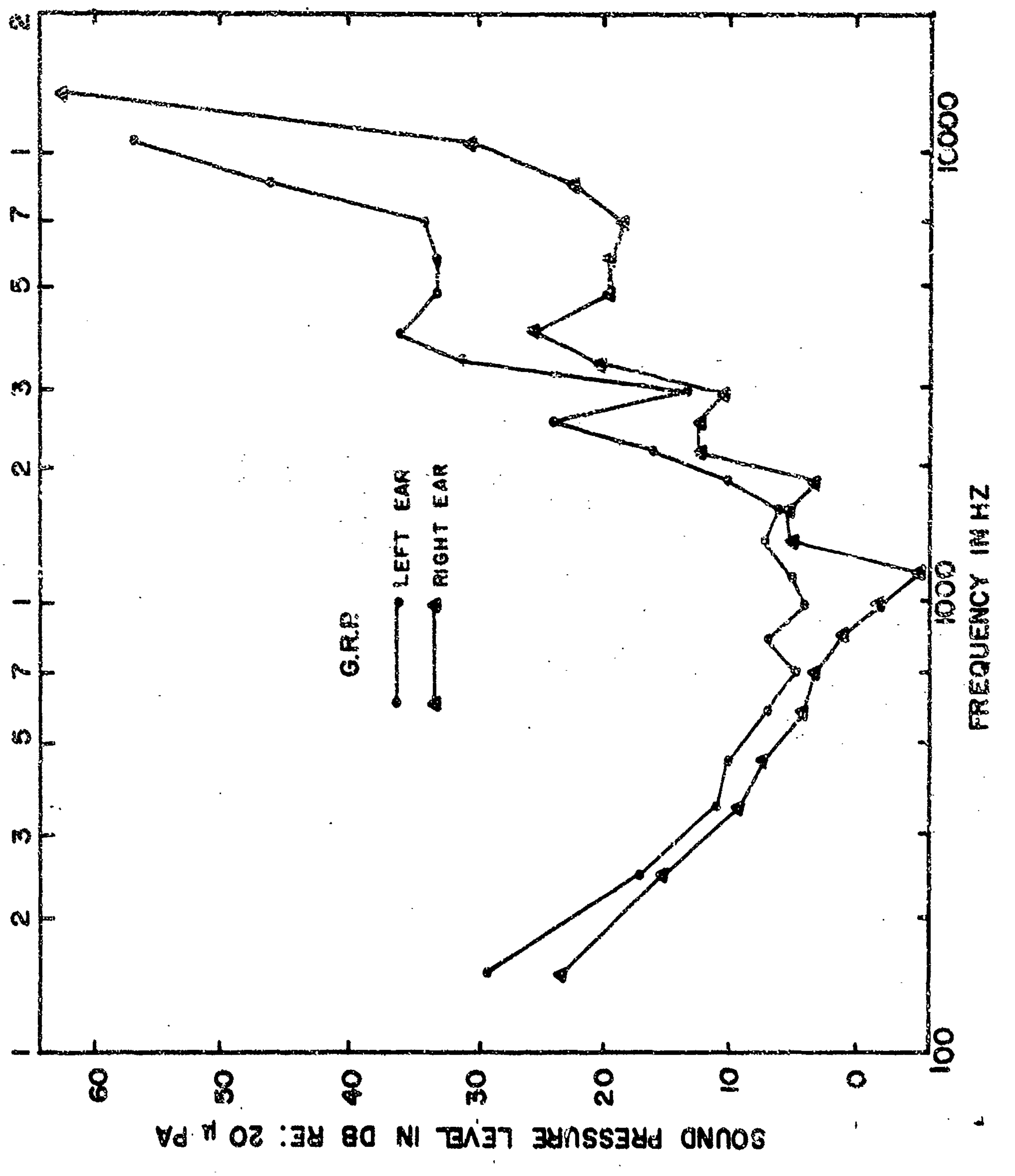
G.R.P.
LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
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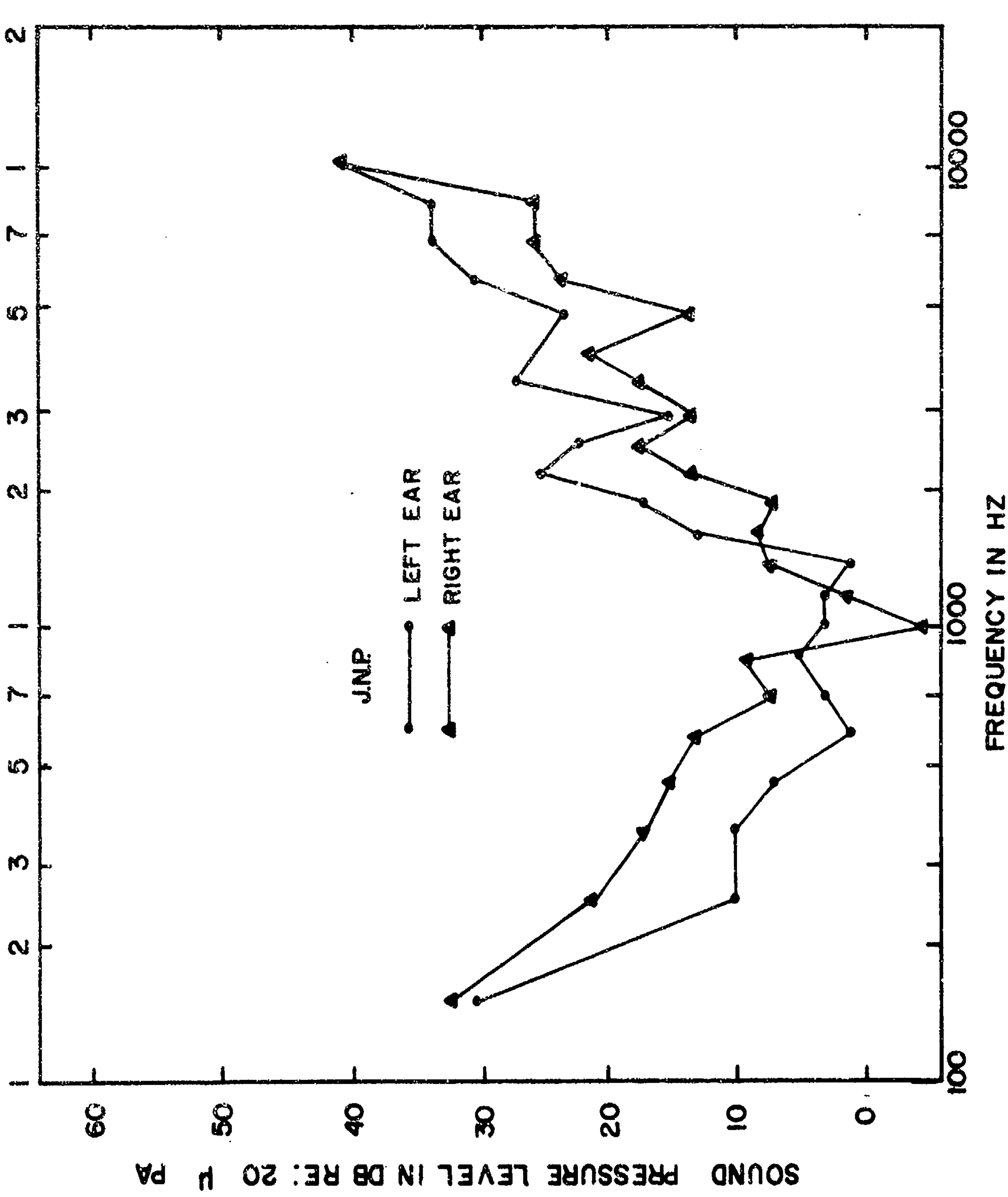
J.N.P.
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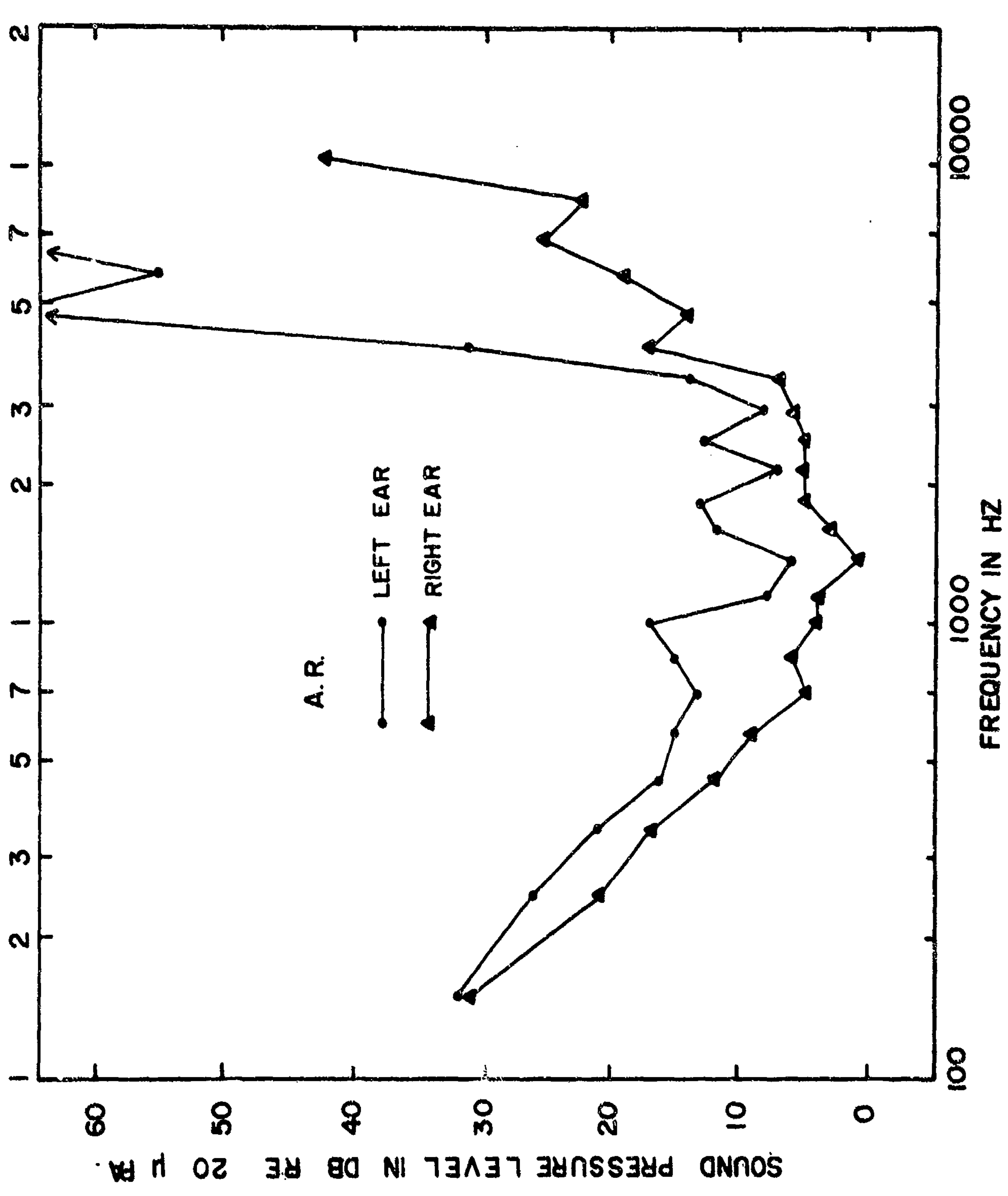

A. R.
LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
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SOUND PRESSURE LEVEL IN DB RE 20 μ PA.
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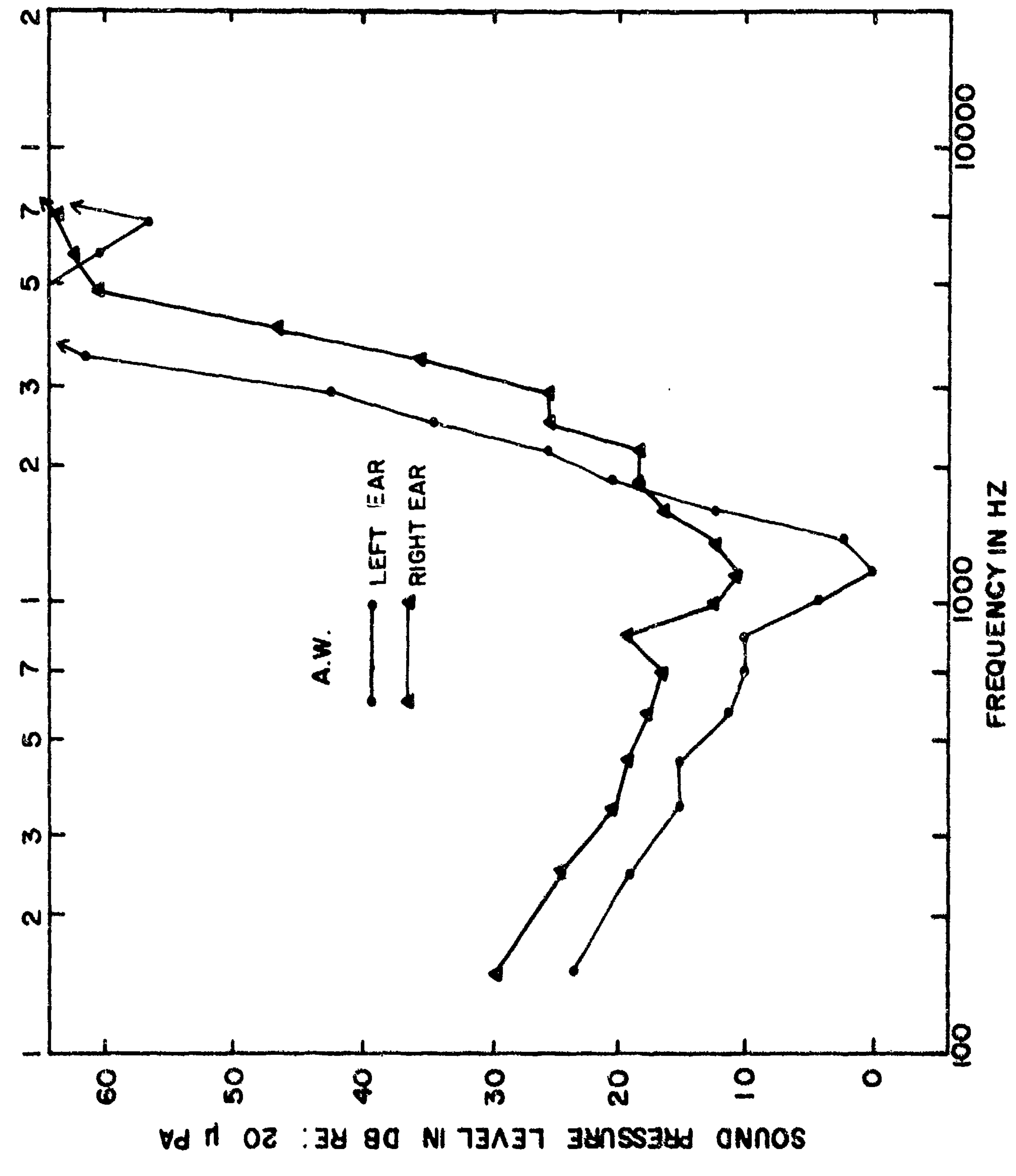
A.W.
LEFT EAR
RIGHT EAR
FREQUENCY IN HZ
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